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A
MANUAL
OF
GEOGRAPHICAL SCIENCE,

MATHEMATICAL,
PHYSICAL, HISTORICAL,
AND
DESCRIPTIVE.

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NUAL OF GEOGRAPHICAL SCIENCE.

PART THE FIRST,

CONTAINING

MATHEMATICAL GEOGRAPHY,

By REV. M. O'BRIEN, M.A., F.R.S.

PROFESSOR OF NATURAL PHILOSOPHY AND ASTRONOMY IN KING'S COLLEGE, LONDON.

PHYSICAL GEOGRAPHY,

By D. T. ANSTED, M.A., F.R.S.

PROFESSOR OF GEOLOGY IN KING'S COLLEGE, LONDON.

CHARTOGRAPHY,

By J. R. JACKSON, F.R.S.

LATE SECRETARY OF THE ROYAL GEOGRAPHICAL SOCIETY.

THEORY OF DESCRIPTION AND GEOGRAPHICAL TERMINOLOGY,

By REV. C. G. NICOLAY, F.R.G.S.

LIBRARIAN OF KING'S COLLEGE, LONDON.

PREFACE.

AT the present time, when so many works on the subject are before the public, a MANUAL OF GEOGRAPHY may seem to require more than ordinary preface; nevertheless, a short one may explain the object of its publication.

Hitherto, those intended to be used in education have been rather compendious works of reference, than introductions to the study of a science, and are often overloaded with details, while general principles are omitted.

In the present work, an attempt has been made to avoid these evils, and so to classify, arrange, and systematize the information contained in it, that it may be immediately available both to the teacher and to the scholar; and by the omission of all non-essential details, whether political, statistical, or topographical, to confine the attention to the principal subject. How far the attempt has been successful, those must decide for whose benefit it has been made.

Although the First Part may appear to be composed of distinct and separate treatises, it is presumed that, on consideration, they will be found to form a consistent whole,—each part being, notwithstanding, complete in itself;—that Professor O'Brien's mode of working astronomical problems by construction, the explanation of the form and use of the more simple instruments, and other things not usually found in the mathematical portions of geographical works, will be readily accepted, by the unscientific reader, in the place of the barren outlines of astronomy and paradoxical problems in the use of the globes, which made this science so unpalatable in our youthful days. In the portion devoted to Physical Geography, Professor Ansted's classification of great leading facts may well compensate for the absence of minute details; while in the chapter on Chartography, Colonel Jackson's intimate acquaintance with the various modes adopted to portray the varying features of the surface of the globe, will enable the reader to peruse in a condensed form, information not easily accessible elsewhere; and in those on the Theory of Description and Geographical Terminology, the effort which has been made, on the one hand, to develop a system, and on the other, to pursue inquiries hitherto comparatively neglected, will, it may be hoped, not only facilitate the attainment of knowledge now, but lead to its extension hereafter.

The geographical knowledge of the ancients, the principal use of which is to illustrate ancient history, being limited in its extent, and derived from those who were, for the most part, entirely ignorant of geography, in the more enlarged acceptation of the term; "The world as known to the ancients" must of necessity be considered topographically; but the world as known at the present time, will be considered first as a whole, then in its larger divisions and minuter sub-divisions, whether natural or civil. In this, which forms the Second Part of the work, the less essential details have been omitted, as generally accessible in Geographical Gazetteers. Normal figures and sections have been introduced, in the belief that their general adoption, in the study of Geography, will much facilitate the acquirement of accurate knowledge.

In the Atlas attached to this work, all the principal facts of Physical Geography will be found compressed within less than ordinary limits, but, it is believed, well defined and without confusion, and fully sufficient for the purposes of elementary study. The compilers have freely availed themselves of the labours of their predecessors, yet the work has features peculiar to itself; among these may be mentioned the omission of names of places in the maps generally, and confining them to a Reference Map, so that the attention may not be distracted from the more immediate object; a comparative Chart of ancient and modern Geography and geographical discovery, and an attempt to express by reversed shading the vertical contour of the surface of the land, from which, at a glance, a general idea, not only of extent but of elevation, may be obtained.

C. G. N.

PART III. — Organization.

CHAPTER X.

CHAPTER XIII.

Theory of Description and Geographical Terminology.

CHAPTER I.

CHAPTER II.

MATHEMATICAL GEOGRAPHY.

By Rev. M. O'Brien

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INTRODUCTION.

THE importance of Astronomical and Optical knowledge to the practical Geographer is so obvious, that it will not be necessary to say anything on the subject here; and we shall therefore, without further preface, proceed to state briefly the nature and extent of the information which we propose to give the reader on the subjects of Astronomy and Optics.

In the first place, then, we must observe, that the space allotted to Astronomy in the present Geographical Treatise is, of necessity, very limited, and therefore we must follow one of two courses in treating of the subject; we must either give a general outline of the whole science, without entering into particulars, or we must select some portion of it of special importance to the Geographer, and develop that at some length, so as to make it practically useful.

We prefer taking the latter course, for two reasons: First, because the space to which we are restricted would only allow us to give a very unsatisfactory outline of Astronomy in general; and, secondly, because, though the greater part of Astronomy has some bearing, directly or indirectly, on Geography, there is one topic of paramount importance—namely, the means which Astronomy affords of determining *position on the earth's surface;* the great practical problem which the Geographer has to solve by means of his Astronomical information being—to determine the relative positions of the various places he may happen to visit.

We shall therefore devote the space here allowed us to the explanation of Astronomical Principles, so far as they have immediate reference to this important problem, and no farther. We shall suppose that the reader is a traveller who is anxious to know just enough of Astronomy to enable him to determine the *Meridian*, the *Latitude*, and the *Longitude* of any place, and that he has little or no acquaintance with the technicalities of mathematics. We shall, with this view, explain generally the *apparent* motions of the heavenly bodies, dwelling but little upon the *real* motions. We shall describe at some length the positions and appearances of the different groups of stars or constellations, this being a most essential part of the subject practically. As regards Optical science, we shall explain as much as is necessary, in order to understand the construction and use of the Astronomical Telescope, as employed to determine *direction*, and of the Astronomical Microscope, as employed to *subdivide space;* we shall show how the Portable Transit Telescope is to be adjusted, and how it may be made use of in determining everything the Geographer requires to know. We shall not have space to say much respecting other Astronomical instruments; but this will not signify, as the Transit instrument is capable of being used with the greatest advantage for every purpose the Geographer has in view, and requires, on his part, no knowledge of what are called the Astronomical corrections. It is on this account that we shall dwell more on the Transit Telescope, and say but little respecting other instruments.

The following is a brief outline of the subject, as we shall here treat of it:—

Chapter I. contains a preliminary statement of the more obvious celestial phenomena—The Fixity and Permanency of the Stars and Constellations—The Circumpolar Rotation—The Proper Motions of the Sun, Moon, and Planets.

Chapter II.—The Celestial Sphere and its Circles. The Constellations described, in order that the reader may make himself familiar with the localities and appearances of the principal stars. In this and the previous chapter we have thought it advisable to introduce a certain amount of information respecting the numerous allusions in ancient writers to the celestial phenomena, and especially the constellations; for a dry description of the stars, without something of this kind, would be scarcely readable, and our object, of course, must be to make the subject not only useful, but, as far as we can, interesting also.

Chapter III.—Astronomical Terms explained—Measures of Time.

Chapter IV.—A Method of solving Astronomical Problems by Geometrical Construction with Rule and Compass. This method consists of the Dissection, if we may so speak, of a solid angle or spherical triangle, so as to represent its six parts on flat paper by construction. All problems usually given in what is called the 'use of the globes,' may be solved by this method with considerable accuracy. It has also the advantage of requiring no mathematical knowledge on the part of the reader; at the same time it leads very simply to all the mathematical formulæ used in Astronomy.

Chapters V. & VI.—The Telescope and Microscope, as used in Astronomy, with the optical principles upon which their construction depends, explained. The Micrometer and Vernier. In Chapter V. some account is given of the optical phenomena which have immediate connexion with Astronomy, such as reflection, refraction, stellar aberration.

Chapter VII.—The Transit instrument, its adjustments, and the method of observing with it.

Chapter VIII.—The Geographical Uses of the Transit instrument.

Chapter IX.—Hadley's Sextant, Altitude Instrument.

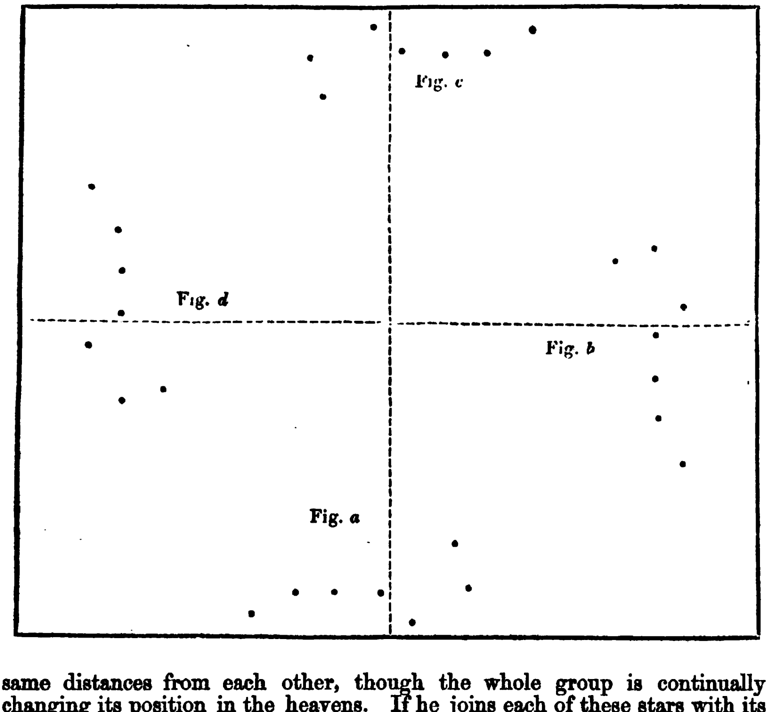
In Chapters V. & VI. we have introduced a little more optical matter than is usual in a treatise on Geography; because our object is, not to write a formal treatise on Astronomy, but to give such information to a person, ignorant of Astronomy and Optics, as will enable him to understand the instruments and principles by which the relative positions of places on the earth's surface are determined.

CHAPTER I.

GENERAL STATEMENT OF THE CELESTIAL MOTIONS.

I. *Of the Firmament.*

THE first fact that is noticed by any one watching the heavens at night is, perhaps, the fixity and permanency of the different groups of stars (or constellations as they are called), notwithstanding the gradual change of position which they all appear to undergo from hour to hour during the night. These constellations always exhibit the same form and appearance, though they are ever on the move. For instance, if the observer fix his attention upon the seven well-known stars, commonly called the Wain, the Plough, or the Great Bear, he will perceive that they always preserve the same distances from each other, though the whole group is continually changing its position in the heavens. If he joins each of these stars with its neighbour by drawing imaginary lines, the figure he so forms will be always the same, though he will sometimes see it as is represented in fig. *a*, sometimes as in fig. *b*, sometimes as in fig. *c*, and sometimes as in fig. *d*.



2 If he continues to watch this or any other of the constellations for years, he will never perceive any change of form; and we may extend this statement to many centuries of past time, for we have evidence, from astronomical records, and the allusions of ancient writers, that the arrangement and grouping of the stars on the celestial vault has ever been the same, with a few remarkable exceptions hereafter to be noticed.

3 In ancient times, before calendars were known, the rising and setting of the constellations were the chief guides of the shepherd, and the tiller of the ground, in determining the progress of the seasons, and this made men in general much more familiar with the appearances of the stars than they are now. We therefore find continual mention of the constellations in the works of antiquity, and especially in the poets. To give a few examples, we find the following lines in *Hesiod, Opera et Dies,* which we shall quote at length, on account of their astronomical interest:—

'But when Orion and Sirius have come into the middle of the heavens, and the rosy-fingered Aurora has beheld Arcturus, then O Perses, gather all the grapes home.'*

'But when at length the Pleiades and the Hyades and the mighty Orion have set, then be mindful of ploughing in time.'†

'But if the desire of dangerous navigation has taken possession of you, when the Pleiades, flying the fierce strength of Orion, have at length set in the dark sea, then surely storms of wind will blow on every side.'‡

Another remarkable passage is found at the beginning of the Second Book, line 381:—

'At the rising of the Pleiades the daughters of Atlas, begin to reap, but when they set, to plough. These stars become invisible for forty days and nights; but they appear again, as the year rolls round, when first the scythe is sharpened.'§

4 The *Fasti* of Ovid, which is a poetical calendar, alludes to almost all the constellations of the heavens, making use of their risings and settings as marks and signs, not only of the four great divisions of the year, the seasons, but also of months and subdivisions of months. In fact, there is scarcely a week which is not marked in the *Fasti* by some particular astronomical note. Thus, in the month of May, we have, among several others, the following allusions to constellations:—

VI No. (2nd of May.)

Pars Hyadum toto de grege nulla latet.
Ora micant Tauri septem radiantia flammis,
Navita quas Hyadas Graius ab imbre vocat.

V No. (3rd of May.)

Nocte minus quarta promet sua sidera Chiron
Semivir.

II No. (6th of May.)

Scorpius in cœlo, cum cras lucescere Nonas
Dicimus, a media parte notandus erit.

II Id. (14th of May.)

Pleiadas adspicias omnes, totumque sororum
Agmen; ubi ante Idus nox erit una super
Tum mihi non dubiis auctoribus incipit æstas;
Et tepidi finem tempora veris habent.

VI Kal. (27th of May.)

Auferat ex oculis veniens Aurora Booten:
Continuaque die Sidus Hyantis erit.

5 We have still remaining a formal account of all the constellations, in a philosophical poem, formerly held in great repute, called the *Phænomena* of Aratus, the same quoted by St. Paul in his address to the Athenians. This poem was founded upon a description of the celestial sphere by Eudoxus, a work of much celebrity in ancient times, and probably compiled from earlier astronomical writers. The description of the constellations by Aratus is not very accurate, owing, not only to the imperfections of the work from which he drew his materials, but also probably from the fact that he either overlooked, or very imperfectly allowed for, the changes in the rising and setting of the constellations caused by a change in the observer's latitude. This poem was commented upon by many celebrated astronomers, and among the

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[*] Εὖτ' ἂν δ' Ὠρίων καὶ Σείριος ἐς μέσον ἔλθῃ
οὐρανόν, Ἀρκτοῦρον δ' ἐσίδῃ ῥοδοδάκτυλος Ἠώς,
ὦ Πέρση, τότε πάντας ἀπόδρεπε οἴκαδε βότρυς.

[†] αὐτὰρ ἐπὴν δὴ
Πληιάδες θ' Ὑάδες τε τό τε σθένος Ὠρίωνος
δύνωσιν, τότ' ἔπειτ' ἀρότου μεμνημένος εἶναι
ὡραίου.

[‡] Εἰ δέ σε ναυτιλίης δυσπεμφέλου ἵμερος αἱρεῖ,
εὖτ' ἂν Πληιάδες σθένος ὄβριμον Ὠρίωνος
φεύγουσαι πίπτωσιν ἐς ἠεροειδέα πόντον,
δὴ τότε παντοίων ἀνέμων θύουσιν ἀῆται.

[§] Πληιάδων Ἀτλαγενέων ἐπιτελλομενάων
ἄρχεσθ' ἀμήτου· ἀρότοιο δὲ δυσομενάων.
αἳ δ' ἤτοι νύκτας τε καὶ ἤματα τεσσαράκοντα
κεκρύφαται, αὖτις δὲ περιπλομένου ἐνιαυτοῦ
φαίνονται τά πρῶτα χαρασσομένοιο σιδήρου.

rest, by Erastosthenes and Hipparchus. It was partially translated into Latin by Cicero, when a very young man, and this translation is still extant. Eudoxus died about 370 B.C. This work, though rough and imperfect, is a valuable relic of the ancient Greek astronomy.

6 But it is to Ptolemy, the Alexandrian astronomer and geographer, that we are indebted for nearly all the accurate information we possess respecting the state of astronomy before the Christian era. He was himself an observer, and, considering the imperfection of his instrumental means, his optical measurements deserve great praise. But the great service he did to astronomy was by compiling with accuracy the observations of previous astronomers, and especially of Hipparchus. In the 7th and 8th Books of his celebrated work, the *Megale Syntaxis*—or, as it was called by the Arabs, *Almagest*—we have the apparent places of the stars on the celestial sphere accurately put down from his own observations, compared with those of the great astronomer, Hipparchus. The catalogue of the stars by Hipparchus, who flourished about 150 years B.C., is lost, but its substance is preserved in Ptolemy's *Syntaxis*. Ptolemy flourished about A.D. 130. The Chaldeans made great advances in astronomy in early times, and Ptolemy often quotes their observations, though none earlier than B.C. 720.

7 From all these numerous sources of information as to the appearance of the heavens in early times, we derive ample evidence that the various groups of stars which we now see in the heavens have always exhibited the same appearances and configurations, that they occupy the same relative positions now as in olden time, and that no changes have taken place in the general arrangement of the stars, at least none but minute changes, which are not sensible to the eye unaided by instruments. Minute changes have indeed occurred in the places of the stars, but it requires the most perfect and delicate instruments to perceive them.

8 It is, in a great measure, this permanency and fixity of the stars in the heavens that renders astronomy of such importance in practice. When astronomers have once made accurate observations on any particular star, and entered its position in their catalogues, there it remains for centuries, an unchangeable mark in the heavens, for the use of future observers—a mark both of time and place, by which the sailor can guide his ship with perfect safety over the ocean, and the geographer construct his maps and charts with unerring fidelity. A star thus determined is a celestial time-piece, that knows no error or variation, not only marking minutes and hours, but years and centuries; serving, at the same time, to regulate a watch, and to guide the chronologer through the darkness of past ages.

9 It is not surprising that the fixity and permanency of the constellations should have led men to form the opinion that the expanse in which the stars appear to be placed is no empty space, but a vault of durable and firm structure. Hence the meaning of the Latin word, *firmamentum*, which has passed into our own language as *firmament;* and of the Greek word, στερεωμα, *stereoma*, which is derived from στερεως, *firmus*, or *firm*. Stereoma is the word in the Septuagint which is translated *firmament* in our version of the book of Genesis. The corresponding Hebrew word, however, contains no allusion to any firmness, but simply signifies space, or expansion. The word star (coming, as it does, from αστηρ) is not derived from the same root as *stereoma*, but from the negative, signifying *unsteady*, no doubt in allusion to the twinkling light of the stars.

10 The opinions of ancient philosophers as to the nature of the stars were very various. (*See* Plutarch's *Moralia de Placitis Philosophorum*, lib. II.) Many supposed them to be nothing but bright ornaments, or, as it were, nails fixed in the crystalline sphere, or firmament. (ἥλων δίκην καταπεπηγέναι τῷ κρυσταλλοειδεῖ.) Anaxagoras said that they were stones flung up from the earth, and kindled by the rapid whirling motion of the æther, (τῇ δ' εὐτονίᾳ τῆς περιδινήσεως ἀναρπάζοντα πέτρος ἐκ τῆς γῆς, καὶ καταφλέξαντα τούτος ἠστερικέναι.) Heraclides and the Pythagoreans said that each star was

a world, like the earth; and the same view was held by the followers of Orpheus. A great variety of opinions prevailed respecting the nature, distance, and magnitude of the heavenly bodies, most of which are stated in the work of Plutarch already referred to.

II. *Of the Circumpolar Motion of the Heavens.*

11 At the same time that an ordinary observer notices the permanency of form and relative position of the various groups of stars, he perceives that every star is moving slowly and steadily; an hour is sufficient to convince him of this. Let him fix his eye on any particular star—say, for instance, one of the seven, in the Great Bear—and let him mark its position with reference to some terrestrial object, (not too near him,) such, for instance, as the top of a tree or chimney, or the ridge of a roof, and he will soon perceive that the star does not continue in the same place. A look at the Great Bear at five or six o'clock of a winter's evening, and again at eleven or twelve o'clock, will show the motion of the heavens in a striking manner; at the first time it will be seen in the position represented by fig. *a;* at the second time, in that represented by fig. *b.* At five or six in the morning the figure will be inverted, as in fig. *c.* At 12 o'clock in the day, if the stars were seen, (as they can be through a telescope,) they would appear as in fig. *d.* At the same hour in the evening, the stars will come again into the same position.

12 With a little care, three facts may be noticed respecting the motion of the heavenly bodies:—*First,* That they all describe parallel circles about one point of the heavens, called the North Pole, (supposing the observer to be in the northern hemisphere of the earth.) *Secondly,* That they all complete their motion in the same time, coming back to the same positions every twenty-four hours. *Thirdly,* That this circular motion is perfectly uniform, each circle—i. e., each 360°, being described at the rate of 15° per hour, or 1° in every four minutes of time.

13 To observe the truth of these facts, some simple instrument will be necessary, as, for instance, a little telescope mounted in the following way:—

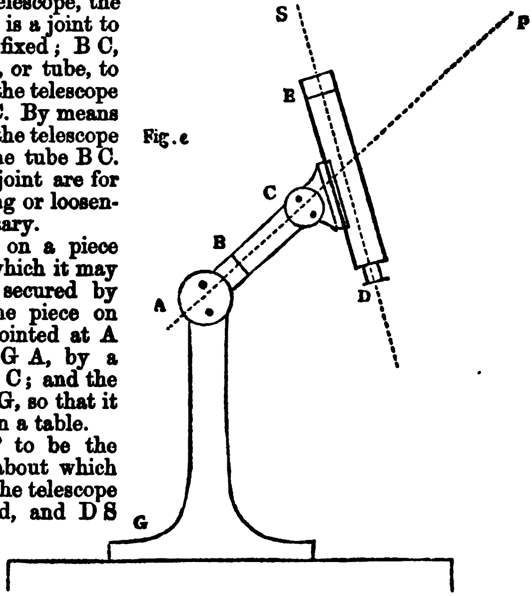


Fig. e

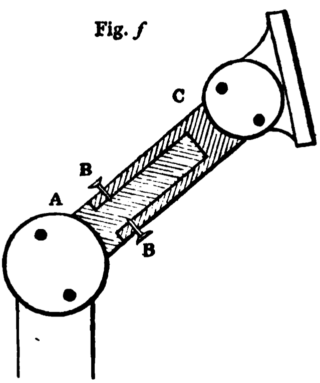
E D (fig. *e*) is the telescope, the eye-hole being at D; C is a joint to which the telescope is fixed; B C, a short hollow cylinder, or tube, to the extremity of which the telescope is jointed by the joint C. By means of this joint we may set the telescope at different angles to the tube B C. The two holes in the joint are for the purpose of tightening or loosening it, as may be necessary.

The tube B C fits on a piece shown in fig. *f,* round which it may be moved; and it is secured by little screws B B. The piece on which the tube fits is jointed at A to the upright stem G A, by a joint similar to that at C; and the stem has a heavy base, G, so that it may stand steadily upon a table.

14 Supposing A P to be the direction of the axis about which the tube B C (carrying the telescope with it) may be turned, and D S the direction in which the telescope looks, then by making the line A P point to the

pole, and the line D S to any particular star, it will be found, that by turning the tube B C round, without altering the inclination of the line D S to the line A P, we may always make the telescope point to the star. This evidently shows that the line D S, drawn in the direction of the star, always makes the same angle with the line A P drawn in the direction of the pole—i. e., that the star always preserves the same distance from the pole, and therefore that it describes a circle about the pole; and this being true, as will be found, for all the stars, it follows that they all describe parallel circles about the pole.

Fig. *f*



15 By pointing the telescope towards a star, leaving it in that position for twenty-four hours, and then looking again through it, it will be found that the star comes back to its original position in twenty-four hours.

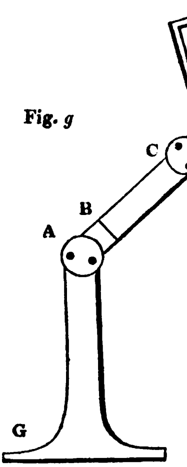
16 This will be found true at all hours, and therefore it follows that the motion of the star is uniform—i. e., that it always moves at the same rate.

17 To use this instrument as above described, the position of the Pole in the heavens must be known in order to direct the line A P towards it. The method of finding the Pole by means of a star which is near it, called the Pole Star, will be explained in the next chapter. The Pole is about a degree and a half from the Pole Star. We shall show in the next chapter how the instrument is to be set, by means of the Pole Star and certain other stars of the constellation called the Little Bear, so that the line A P may point to the Pole—at least, sufficiently near the Pole for our purpose.

18 This instrument need not be made very accurately, as it is not capable of being used with any great nicety, but only in a rough way, to observe the general motions of the heavenly bodies, such as the diurnal rotation of the Stars, the annual motion of the Sun, the motions of the Moon and Planets. If a better instrument cannot be procured, such an instrument as this will be found very useful to the beginner, as the observation of celestial phenomena, even in a rough way, is not only highly interesting, but very instructive as far as regards practical astronomy.

19 Two graduated circles, which may be made of pasteboard or paper pasted on wood, ought to be added to the instrument as above described—one at C, to measure the angle which the line S D makes with the line P A, and the other at B, to measure the number of degrees through which we turn the tube B C about the polar axis A P. It will be sufficient to have these circles graduated to degrees, as they could not be expected to give smaller measures with any degree of accuracy.

Fig. *g*



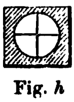


Fig. *h*

Fig. *i*

20 Instead of the telescope, a rod with a pair of ordinary sights may be substituted, as is shown in fig. *g*, M and N being the sights. The sight M which is supposed to be next the eye, is a small flat piece of brass with a hole in it, as is shown in fig. *i*. The other sight is a similar piece of brass, only

it has two pieces of thin wire drawn across the hole at right angles, as is shown in fig. *h*, in order to mark the centre of the hole. The eye being placed near M, sees these cross wires, and it should look in such a manner as to make the wires appear to divide the hole M into four equal parts—i. e., the point where the wires cross each other, or as it is called, the centre of the cross wires, should appear to coincide with the centre of the hole M.

When this is done, any object, such as a star, which is seen at the centre of the cross wires, is in the direction in which the sights point—i. e., the line joining the centre of the hole M, and the centre of the cross wires points to the star.

21 The line joining the centre of the hole M, and the centre of the cross wires, is called the *Line of Direction of the Sights*, and more frequently, the *Line of Collimation*. Collimation is derived from the Latin word *collineo*, or *collimo*, (from *con* and *lineo*,) which signifies, *to direct one thing in a straight line towards another*—i. e., *to aim at*. This is a line of great importance in astronomy, and we shall speak more of it presently.

22 The telescope (if the instrument have a telescope instead of sights) should be furnished with cross wires in the focus, to mark its line of direction or collimation. The magnifying power of the telescope may be very small. A single object-glass of three or four inches focus, and a single eye-glass of one or two inches focus, will form a sufficiently good telescope.

With an instrument of this kind, any person may satisfy himself respecting the uniform circumpolar motion of the heavenly bodies: first of all, that each heavenly body always keeps at the same distance from the pole, or, in other words, that it describes a circle about the pole; secondly, that it completes this circular motion in twenty-four hours; thirdly, that it always moves at the same rate, namely, 15° per hour, or 1° in four minutes.

23 To prove these facts with accuracy, it is necessary to employ much more perfect and delicate instruments than the above. Astronomers employ what is called a *Transit instrument*, which we shall presently describe at some length, to observe the time at which each heavenly body comes on a particular line called the *Meridian*, and for this purpose it is necessary to have a first-rate clock to subdivide time with accuracy to a fraction of a second. To determine how far any heavenly body is from the pole, astronomers use another instrument, called a *Mural Circle*, or an *Altitude Instrument*. Both these instruments are extremely simple as regards their motions, and are capable of wonderful accuracy when well made. A third instrument, called an *Equatorial*, is made use of for measuring small spaces and distances in the heavens. These three instruments, fixed in a convenient building, together with the clock, and some minor instruments, make an Astronomical Observatory. The rude instrument above described may be made to represent any one of these three great, or, as they are called, *capital* astronomical instruments. If the line A P be made vertical, and the tube B C fixed in such a position that the line D S may be in what is called the *meridian plane*—i. e., in the vertical plane which contains the pole, then the instrument represents a Transit telescope. If, in addition to placing the instrument thus, a graduated circle be fixed at C, to measure the inclination of the line D S to the line A P, it represents a Mural Circle. If A P be fixed so as to point to the pole, as originally supposed, then the instrument represents an Equatorial.

III. *The Earth's Rotation the Cause of the Apparent Circumpolar Motion of the Heavens.*

24 The circumpolar motion of the heavenly bodies may be either an actual and real motion, or it may be only apparent, being caused by an opposite motion of the spectator. If we suppose the Earth to be a round body, as it may be proved to be by observation and measurement, and to revolve from west to east once in twenty-four hours, about an axis passing through the two poles, this will sufficiently account for the apparent motion of the heavenly

bodies from east to west about the pole; for a motion of the earth round its axis from west to east would evidently make the stars appear, to any observer on the Earth's surface, to move about the same axis in the contrary direction, from west to east. The natural impression, on perceiving the circumpolar motion of the heavens, is, of course, that it is a real motion; and this was the opinion of mankind, with a few exceptions, for many ages. The inquisition compelled Galileo to abjure the Copernican doctrine, (which taught both the annual motion of the Earth about the Sun and its diurnal motion about its axis,) and decreed, 'that the proposition, that the Earth is not the centre of the world, nor immoveable, but that it moves, and also with a diurnal motion, is absurd, philosophically false, and theologically at least erroneous in faith.' The story that Galileo, on rising from his knees after the abjuration, whispered, 'E pur se muove'—'It moves nevertheless'—is well known.

25 The doctrine, that the Earth was the immoveable centre of the universe, which was the basis of the Ptolemaic system, was universally received until the time of Copernicus, who published his celebrated work, *De Revolutionibus Orbium Cœlestium*, in 1543, in which he refutes, but in a cautious and hypothetical manner, the complex system of Ptolemy, which taught that the stars were carried round the Earth daily by an enormous crystalline sphere, and that the motions of the Sun, Moon, and planets, were produced in the same manner. Considering the enormous distances and magnitudes of the heavenly bodies, and the unnatural machinery of cycles and epicycles by which the planetary motions were accounted for, Copernicus felt that some other hypothesis respecting the celestial revolutions was necessary to satisfy his mind. He found that some ancient philosophers had taught the motion of the Earth about its axis and its annual motion about the Sun. Carefully and cautiously considering these views, he at length came to the conclusion that the Sun is the centre of the universe, and that the Earth revolves not only about the Sun, but also about its own axis, whereby the apparent diurnal motion of the stars is produced. These views he published in the work above alluded to, which was dedicated to the pope, Paul III. After the time of Galileo, the Copernican system prevailed, and the Ptolemaic was neglected, though the works of both astronomers were still condemned as heretical by the Romish church. Mr. Drinkwater, in the *Library of Useful Knowledge*, states, that both were in the *Index Expurgatorius* for 1828, with the words 'Nisi corrigatur.' But on this point see Lyell's *Geology*, p. 58 (7th ed.)

26 The proof of the Earth's rotation about its axis is, in a great measure, derived from the fact that it simply, naturally, and reasonably accounts for the apparent diurnal motion of the heavens, which the Ptolemaic system does not. In addition to this, the peculiar figure of the Earth, which is found to be nearly spherical, but somewhat flattened at the poles and protuberant at the equator, indicates the existence of a centrifugal force, caused by rotation about an axis. Experiments on pendulums afford clear evidence of the existence of this centrifugal force. Experiments on falling bodies, which must be considered accurate and satisfactory, have been made, and it appears from them that a body let fall from a considerable height always falls a little to the east of the vertical; this can only be accounted for by the Earth's rotation. Observation shows that the Sun, Moon, and planets, revolve from west to east about their axes, and it is not unreasonable to conclude that the Earth is not an exception to what appears to be the rule of the planetary motions.

27 There is another proof that the Earth is not fixed, of the most convincing kind, derived from the phenomenon of the aberration of light, of which we shall presently speak. By this curious displacement, the Earth's motion is made visible in every star, as it were in miniature, each star describing an apparent orbit, similar to the motion of the Earth. This, however, applies to the motion of the Earth about the Sun.

28 One other consideration tends to confirm the truth of the opinion that the Earth revolves about its axis. It is this, that a most important end is

gained by the Earth's rotation—namely, the axis is thereby kept steady in one position. But for its rotation, the Earth's axis would be continually changing from one direction to another, and the effect of this would be extraordinary vicissitudes of seasons; we should be at one time in the polar regions—at another, in the tropics, subject to rapid and irregular changes of climate, and to violent disturbances of the atmosphere and the ocean. The example of a common spinning-top or hoop is sufficient to show the effect of rotation in keeping a body in one position. It would be a practical impossibility to balance a top by placing it with its point on the ground, without having first communicated to it a motion of rotation; but once make it spin rapidly about its axis, and it will stand steadily on its point—so steadily that it will require a considerable blow to upset it. The same thing is true of trundling a hoop; the rotation communicated to it keeps it so steady that the pressure of the stick upon it sideways does not upset it, but merely causes it to turn slightly out of its course.

29 It is, then, by a rapid motion of rotation that the 'round world is made so fast that it cannot be moved,' not absolutely fixed, it is true, but fixed with its axis in one position, by which means the changes from night to day, and from season to season, become uniform and regular. And no doubt the same important end is gained by the rotation of the Sun, and Moon, and planets, each about its axis, and by the revolutions of the planets about the Sun. It is by a wonderful combination of motion and attraction that the solar system is preserved unchanged, and each planet kept at its proper distance from the Sun. And the rotations and proper motions of the stars, now so clearly made out by astronomers, indicate that the same system pervades the universe. It is, most probably, by their motions and attractions that the stars are preserved, each in its place. Without that perpetual revolution and rotation, and that bond of attraction which unites the remotest systems, the whole universe, as far as we may presume to judge, would drift in confusion in the boundless ocean of space, and become a formless chaos.

IV. *Globular Form of the Earth.*

30 It is not necessary to say much on this point here; that the Earth is a globe may be, and has been, continually proved by actual observation and measurement. The most commonplace observation is sufficient to make the fact evident. In every part of the ocean, the horizon is visibly circular, this proves that the ocean, which covers a considerable portion of the Earth's surface, is globular. The same is true of the great inland lakes which are found in various parts of the world. The appearance of a ship approaching land—the masts first becoming visible, and then the hull, is a familiar proof of the Earth's rotundity. So also is the circular shadow of the Earth, cast by the Sun on the Moon, in an eclipse. The circumnavigation of the Earth, which is no uncommon occurrence, may also be adduced. The best proof is actual measurement; but we could not say anything satisfactory on this point without introducing mathematical technicalities.

V. *Proper Motion of the Sun, Moon, and Planets.*

31 We have stated above, that, *with a few exceptions*, the heavenly bodies always preserve their relative places unchanged, and appear to describe circles about the pole, at the invariable rate of 15° per hour, so completing the whole circuit of 360° in twenty-four hours. We shall now briefly explain what the exceptions are, commencing with the Sun, whose motion in the heavens is the cause of so many important changes to us: those changes from light to darkness, and from heat to cold, which give rise to day and night, and bring about in order the various seasons of the year. We shall then briefly consider the motion of the Moon, and the apparently irregular and anomalous wanderings of the planets which were so satisfactorily unravelled by Copernicus. The annual motion of the Sun, and the monthly revolution

of the Moon, are simple enough at least to ordinary observers, being always from west to east; but the motions of the planets seem to be governed by some complicated law—they sometimes move eastward, sometimes westward, and they sometimes remain stationary. They were supposed in ancient times to wander irregularly over the heavens, and hence they were called *πλανητοι*, or wanderers, by the Greeks, and 'errantes' by the Latins, and sometimes 'vagæ.'

32 These motions and appearances of the Sun, Moon, and planets are beautifully described by Cicero, in the second book *De Natura Deorum*, which is so much to the point, that we cannot do better than transcribe it here:—

'There remains, last of all, and at the greatest altitude above our habitation, surrounding and keeping in all things, the expanse of heaven, which is also called the æther, the extreme region and boundary of the universe; in which, in the most wonderful manner, bodies of fire perform their appointed motions: among which the Sun, though much exceeding the Earth in magnitude, revolves about it. And he by his rising and setting makes day and night; and at one time approaching (towards the pole), and at another receding, he turns back twice every year, at opposite points of his course—(i. e., at the solstices at midsummer and midwinter); between which, during one period he chills the Earth, as it were, with sadness, and during another gladdens it so that it seems to rejoice with the heavens. The Moon also, which, as mathematicians show, is more than half the magnitude of the Earth, wanders over the same part of the heavens that the Sun does; at one time being in the same quarter with the Sun, and at another time in the opposite, she transmits to the Earth the light she receives from the Sun, and she undergoes various changes of brightness; also, at one time, she comes between us and the Sun, and obscures his light, and at another time, falling into the shadow of the Earth, which comes between her and the Sun, she becomes suddenly eclipsed. In the same part of the heavens also those stars, which we call wanderers, are caused to revolve about the Earth, rising and setting like the Sun and Moon; and the motions of these stars are sometimes direct and sometimes retrograde, and sometimes also they become stationary; and nothing is more wonderful, nothing more beautiful, than this spectacle. After these, comes an immense host of fixed stars,' &c. &c.*

He then goes on to describe the different constellations, and in so doing, he quotes a considerable portion of the astronomical poem of Aratus.

33 The motions of the Sun, Moon, and planets are twofold:—*first*, they partake of the same apparent circumpolar motion as the fixed stars, which, as we have explained, is caused by the Earth's rotation about its axis; *secondly*, they have other motions which the stars have not, and which are therefore called *Proper* (or peculiar) *Motions*. These motions we shall now describe.

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* 'Restat ultimus, et a domiciliis nostris altissimus, omnia cingens et coercens, cœli complexus, qui idem æther vocatur, extrema ora et determinatio mundi: in quo cum admirabilitate maxima igneæ formæ cursus ordinatos definiunt. E quibus Sol, cujus magnitudine multis partibus terra superatur, circum eam ipsam volvitur. Isque oriens et occidens, diem noctemque conficit, et modo accedens, tum autem recedens, binas in singulis annis reversiones ab extremo contrarias facit: quorum intervallo tum quasi tristitia quodam contrahit terram, tum vicissim lætificet, ut cum cœlo hilarata videatur. Luna autem, quæ est, ut ostendunt mathematici, major quam dimidia pars terræ, iisdem spaliis vagatur quibus Sol: sed tum congrediens cum Sole, tum digrediens, et eam lucem quam a Sole accepit mittit in terras, et varias ipsa mutationes lucis habet: atque etiam tum subjecta atque opposita Soli radios ejus et lumen obscurat, tum ipsa incidens in umbram terræ, quum e regione Solis, interpositu interjectuque terræ, repente deficit. Iisdem spaliis hæ stellæ, quas vagas dicimus, circum terra feruntur, eodemque modo oriunter et occidunt: quarum motus tum incitantur, tum retardantur; sæpe etiam insistunt. Quo spectaculo nihil potest admirabilius esse nihil pulchrius. Sequitur stellarum inerrantium maxima multitudo,' &c. &c.

VI. *Proper Motion of the Sun.*

34 The proper motion of the Sun may be easily observed and made out, by means of the instrument above described, in the following manner. Let the axis A P be directed to the pole, and fixed in that position; then, at different times of the year, let the line D S be pointed to the Sun. It will be easy to see when the telescope, or the rod with sights, points to the Sun, by the shadow it casts on a piece of card fixed at the extremity D, at right angles to the telescope or rod. We may, then, by means of the graduated circle, which we have stated should be fixed at C, measure the angle which the line D S makes with the line A P, and so find how far the Sun appears to be from the pole; i. e., if the angle is 80°, then the Sun is 80° from the pole, if 90°, the Sun is 90° from the pole, if 100°—100°, and so on. We may here observe, that when a heavenly body is 90° from the pole it is said to be in the *equator*, because, if it be 90° from the North pole, it must also be 90° from the South pole—i. e., it is half way between the two poles, its distances from each are *equal*, and it is said to be in the *equator*. The equator is, in fact, that circle every point of which is at equal distances—i. e., 90° from each pole.

35 Now, if we observe the Sun, as we have just stated, we shall find, about the third week in March, that the Sun is 90° from the North pole; and at the corresponding periods of the following months, we shall find that the Sun's distance from the pole will be exhibited, in round numbers, by the following table:—

MONTH.	Sun's distance from North pole.	Sun's distance from Equator.	MONTH.	Sun's distance from North pole.	Sun's distance from Equator.
March . .	90°	0°	October .	102°	12° South.
April . .	78°	12° North.	November.	110°	20° South.
May. . .	70°	20° North.	December .	113½°	23½° South.
June . .	66½°	23½° North.	January .	110°	20° South.
July. . .	70°	20° North.	February .	102°	12° South.
August . .	78°	12° North.	March . .	90°	0°
September	90°	0°			

36 The Sun's distance from the pole in this table may be obtained by using the instrument as above stated; his distance from the equator is of course immediately obtained by taking the difference between his polar distance and 90°. Thus, if the Sun is 70° from the pole, he is 20° above—i. e., north, of the equator, because 20° added to 70° make 90°, and 90° is the distance of the equator from the pole. In like manner, if the Sun is 110° from the pole, he is 20° below—i. e., south, of the equator, for 20° added to 90° make 110°.

37 By inspecting the above table, the Sun's motion towards and from the pole will be immediately evident. About the third week in March he crosses the equator; after this, he moves continually northward, until the corresponding period in June, when he attains his greatest altitude above the equator, about 23½°. After this he begins to move southward, and continues to do so, till about the third week in September, when he again crosses the equator. He continues his motion southward till the third week in December, when he is at the most southerly point of his course, about 23½° below the equator. After this, he returns again, and moves northwards, till he comes back to the equator, about the third week in March.

38 It is to this motion of the Sun towards and from the pole that Cicero alludes, in the words above quoted—'Et modo accedens, tum autem recedens, binas in singulis annis reversiones ab extremo contrarias facit.'

39 The Sun's motion towards or from the pole is quickest when he crosses

the equator, and slowest when he is at the greatest distance from the equator; in fact, about the third week in June, and the corresponding period in December, he is sensibly stationary for some days—i. e., his motion towards or from the pole is scarcely perceptible. This will be easily seen from the following table, in which his motions in March and June, 1849, are compared. A similar table would show his comparative motions in September and December.

Day of the Month.	Sun's distance from Equator.	Day of the Month.	Sun's distance from Equator.
March 15	2° 4′ South.	June 15	23° 20′ North.
„ 16	1° 40′ „	„ 16	23° 22′ „
„ 17	1° 16′ „	„ 17	23° 24′ „
„ 18	0° 53′ „	„ 18	23° 25′ „
„ 19	0° 29′ „	„ 19	23° 26′ „
„ 20	0° 5′ „	„ 20	23° 27′ „
„ 21	0° 19′ North.	„ 21	23° 27′ „
„ 22	0° 42′ „	„ 22	23° 27′ „
„ 23	1° 26′ „	„ 23	23° 27′ „
„ 24	1° 29′ „	„ 24	23° 26′ „
„ 25	1° 53′ „	„ 25	23° 24′ „
„ 26	2° 17′ „	„ 26	23° 22′ „
„ 27	2° 40′ „	„ 27	23° 20′ „

40 From this table we may see that in March the Sun moves northward at the rate of about 24′ per day, or 2° in five days; whereas, in June his whole northerly motion from the 15th day of the month to the 20th is only 7′; and from the 20th to the 23rd his motion is not perceptible.

The position of the Sun, when at his greatest distance from the equator was hence called *Solis Statio*, or the *Solstice*, because he became stationary for a short time at that point. In June, it was called the Summer Solstice, and in December the Winter Solstice. The times in March and September, when the Sun crosses the equator, were called the *equinoxes*, because then all over the world the length of the night is the same, which is not the case except at those particular periods of the year.

41 But the Sun has another proper motion besides that we have just explained, which may be made apparent by means of the instrument above described, and a watch.

The axis A P must be pointed towards the pole as before, and the tube B C must be fixed, so that the telescope or rod with sights, may be capable of moving only in one plane—i. e., about the axis C. If we make the axis C horizontal, the telescope will move in a vertical plane; in fact, in what is called the *Plane of the Meridian*, of which we shall speak more presently. We shall suppose the instrument to be thus disposed, the axis A P pointing to the pole, the tube B C fixed so as not to be capable of turning round, and fixed in such a position that the telescope may move in a vertical plane, or nearly so. Another plane would answer as well, but it will save circumlocution to suppose it to be a vertical plane—i. e., the plane of the meridian.

42 Now at night let the telescope, thus moving in the plane of the meridian, be placed so as to point to any particular star that happens to be at that time in the plane of the meridian. Let the hour and minute shown by the watch be immediately noted. Let a similar observation be made on the same star the next night, and of course about the same hour, and let the hour and minute shown by the watch be again noted. In this way the time, as shown by the watch, in which the star completes its revolution will be determined: for instance, suppose that at the first observation the watch shows twenty minutes past nine, and at the second seventeen minutes past nine; then it follows that the star completes its revolution in twenty-three

hours and fifty-seven minutes, as shown by the watch. We do not suppose the rate of the watch to be perfectly accurate; it should be of course a tolerably good watch, but it is no consequence if it gain or lose a few minutes in the day.

43 Again, let precisely the same observation be made upon the Sun on two successive days, and in this way let the time, as shown by the watch, in which the Sun completes his revolution be determined. In the example above supposed, it will be found that the Sun's time of completing his revolution will be very nearly twenty-four hours and one minute, as shown by the watch. And in all cases, whatever star we make our observations upon, it will be found that the Sun takes very nearly four minutes longer to complete his revolution than the stars do, for all the stars, as we have already stated, will complete their revolutions in exactly the same length of time. The Sun, therefore, is about four minutes later than the stars every day.

44 Now what is the cause of this? It is not the motion of the Sun towards or from the pole, because such a motion would not in any way affect the time of the Sun's coming into the plane of the meridian, it would only make him cross that plane nearer to or further from the pole, as the case might be. The cause must be, therefore, a backward transverse motion —i. e., a motion perpendicular to the motion towards or from the pole, which makes the Sun arrive at the plane of the meridian four minutes late every day—i. e., four minutes later than if the Sun were, like the stars, fixed in the heavens, and only subject to an apparent motion caused by the rotation of the Earth about its axis. If we suppose the watch to be regulated by the stars—i. e., if it shows twenty-four hours as the time of each star's completing its revolution, then, if the Sun crosses the meridian plane at twelve o'clock to-day, he will not cross it to-morrow till about four minutes past twelve. At twelve o'clock to-morrow, therefore, the Sun will be one degree behind the meridian; for in four minutes of time each heavenly body describes one degree of its apparent circular motion, and therefore as the Sun will arrive at the plane of the meridian at four minutes past twelve o'clock, he must be one degree behind that place at twelve o'clock.

45 We have now made out in a rough way the proper motions of the Sun; he has two proper motions, one towards or from the pole, as the case may be, the other a backward motion perpendicular to the former, at the rate of about one degree daily.

By the combination of these motions the Sun appears to describe an oblique circle in the heavens, moving backwards, (that is, from west to east.) Moving in this circle, he crosses the equator, at the time of the equinoxes, at an inclination to the equator of about 23½°. This circle is called the *ecliptic*, because eclipses of the Sun and Moon occur only when the Moon crosses or comes near this circle.

46 The proper motion of the Sun is only apparent, being caused by the Earth's real motion about the Sun. The Earth is one of the planets, being the third in order from the Sun; the planets all revolve round the Sun in planes, but little inclined to each other, and in nearly circular orbits. This is the Copernican theory, and it is the only rational way of accounting for the Sun's apparent proper motion, and the apparent proper motions of the planets—of which we shall speak immediately. Newton's theory of universal gravitation applied to determine the motions of the solar system, confirmed as it is in the most astonishing manner, by predictions of eclipses and occultations, and by solar, lunar, and planetary tables calculated from it, and verified with the greatest exactness by repeated observations, proves beyond doubt the truth of the Copernican theory, as also does the phenomenon of aberration, to which we have already alluded.

47 The apparent motion of the Sun towards and from the pole is caused by the inclination of the Earth's axis to the plane of the ecliptic—i. e., the plane in which the Earth moves round the Sun. If the Earth's axis were perpendicular to this plane, the Sun would always appear to be 90° from the

pole, as is manifest. But this not being the case, the Sun sometimes appears to be nearer to, and sometimes further from, the pole, as the Earth moves round.

48 To show this, we must observe that the Earth's axis remains parallel to itself, or very nearly so, during the year—i. e., it always points in the same direction; also its inclination to the plane of the ecliptic is 66½° in round numbers.

Now, this being the case, suppose E, fig. *a*, to be the Earth's centre, E P

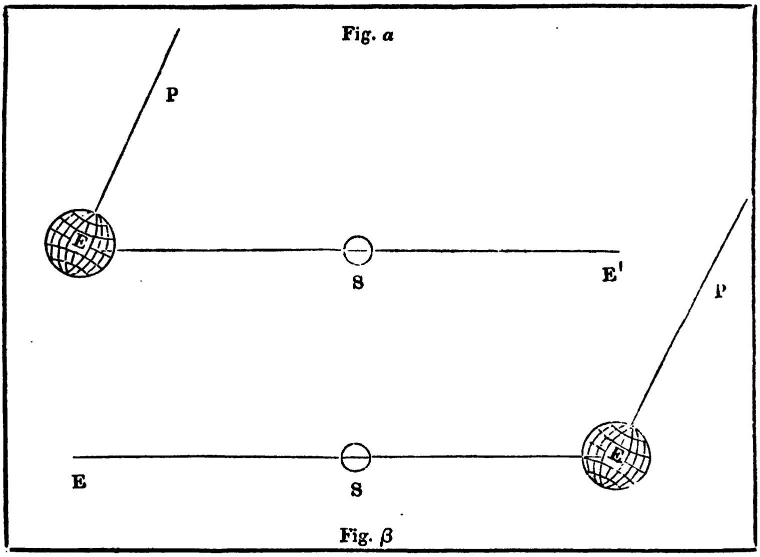
Fig. *a*

Fig. *β*

its axis, and S the Sun, the angle P E S being 66½°; then, in this position of the Earth with reference to the Sun—the polar distance of the Sun—i. e., the angle P E S, is 66½°.

But in six months the Earth will describe half its orbit round the Sun, and therefore come into the position E′, just opposite E on the other side of S, as is represented in fig. *β*; also the axis E′ P will be parallel to its former direction E P, as is shown in the figure. Therefore the angle P E′ S, which is the Sun's polar distance, will be evidently greater than 90°—in fact, as much greater than 90° as P E S is less than 90°; in other words, the Sun will be 113½° from the pole.

49 It appears, therefore, that in one position of the Earth, the Sun will be 66½° from the pole, and in six months after 113½° from the pole. During the six months, the polar distance will gradually increase from 66½° to 113½° being 90° at the end of three months. In the remaining six months of the year, the polar distance will diminish till it becomes 66½° again—namely, when the Earth comes back to the position E.

The Earth in the above figures is supposed to move about S in a plane perpendicular to the plane of the paper. Hence it appears that the supposition of the parallelism of the Earth's axis, as it moves round the Sun, accounts for the changes in the Sun's polar distance.

VII. *Proper Motion of the Moon and Planets.*

50 The proper motion of the Moon is similar to that of the Sun, only about 13 times quicker, and rather irregular, at least, apparently irregular, but really obeying a regular, though complicated law. The Moon's proper motion may be observed by the instrument we have described, and exactly in the same way as the Sun's. It takes place in a circle inclined about 5° to the ecliptic, in which she moves from west to east in less than a calendar month. The following table will best explain the nature of her motion, which, like that of the Sun, is twofold—one motion towards or from the pole, the other a backward motion:—

Day of Month, 1849.	Moon's distance from equator.	Hour that the Moon comes to the meridian plane.
July 1	14° 10′ South.	$9^{h}\,15^{m}$ afternoon.
„ 2	16° 28′ „	$10^{h}\,1^{m}$ „
„ 3	18° 4′ „	$10^{h}\,48^{m}$ „
„ 4	18° 53′ „	$11^{h}\,36^{m}$ „
„ 5	18° 1′ „	$12^{h}\,0^{m}$ „
„ 6	16° 20′ „	$0^{h}\,24^{m}$ morning.
„ 12	1° 8′ North.	$5^{h}\,7^{m}$ „
„ 13	5° 27′ „	$5^{h}\,56^{m}$ „

The proper motion of the Moon is not apparent, but real; the Earth being the body about which the Moon actually revolves.

51 The proper motions of the planets may be observed in the same manner as those of the Sun and Moon; they are much more complicated, as the following table for Mercury will show:—

Day of 1849.	Number of minutes by which Mercury is too late or too soon in crossing the meridian plane each day.	Corresponding motion backward or forward.
January 1	7 minutes late.	1¾° backward.
„ 15	7 „ „	1¾° „
February 1	5½ „ „	1⅜° „
„ 5	4½ „ „	1⅛° „
„ 10	2 „ „	0½° „
„ 11	1½ „ „	0⅜° „
„ 12	1 „ „	0¼° „
„ 13	0 „ „	0° „
„ 14	0 „ „	0° „
„ 15	1 „ too soon.	0¼° forward.
„ 20	3½ „ „	0⅞° „
„ 25	4 „ „	1° „
March 1	2 „ „	0½° „
„ 5	1 „ „	0¼° „
„ 6	½ „ „	0⅛° „
„ 7	0 „ „	0° „
„ 8	0 „ „	0° „
„ 9	½ „ late.	0⅛° backward.
„ 10	1 „ „	0¼° „
„ 15	3 „ „	0¾° „
„ 20	4 „ „	1° „

From this table it is evident that in the first half of January, Mercury was continually moving backward among the stars, (i. e., from west to east,) at the rate of about $1\frac{3}{4}^\circ$ per day. Up to the 13th of February, this daily backward motion became continually smaller, being $1\frac{3}{8}^\circ$ on the 1st of February, $1\frac{1}{8}^\circ$ on the 5th, only $\frac{1}{2}^\circ$ on the 10th. Between the 13th and 14th, Mercury had no proper motion backwards or forwards, and so far became stationary. On the 15th, Mercury began to move forward (i. e., from east to west) at the rate of $\frac{1}{4}^\circ$ per day; on the 20th, this forward motion had increased to $\frac{7}{8}^\circ$ daily; on the 25th to 1°; on the 1st of March it had diminished again to $\frac{1}{2}^\circ$; on the 5th to $\frac{1}{4}^\circ$; and between the 8th and 9th, Mercury became stationary again; after this the motion became again retrograde.

52 From this description of the apparent proper motion of Mercury among the stars, which applies to Venus likewise, it is easy to understand the words of Cicero above quoted, 'quorum motus tum incitantur, tum retardantur, sæpe etiam insistunt.'

We have considered Mercury in the above description on account of his rapid motion, but it is difficult to see him on account of his proximity to the Sun. Venus would be the proper planet to make observations upon with the instrument above described, by the assistance of which, as in the case of the Sun, the proper motions of the planet may be made out.

VIII. *The Complicated Motions of the Planets are explained by supposing that they and the Earth move about the Sun as centre.*

53 The explanation which Copernicus gave of the apparently complex and irregular motion of the planets was, that they all, along with the Earth, move round the Sun as centre. This motion takes place nearly in one plane, (at least as regards the principal planets,) namely, the plane of the ecliptic. All the planets move the same way, which is from west to east—i. e., contrary to the apparent diurnal motion of the heavens, but in the same direction as the Earth's rotation about its axis, which causes that apparent motion.

54 It is the combination of the motion of the planet and that of the Earth, that makes the former appear sometimes to move forward, sometimes backwards, and sometimes to be stationary. To a spectator in the Sun, the motions of the planets would appear simple enough, the Sun being the centre about which they all move. But to a spectator on the Earth, which is not the centre of motion, and which moreover is itself moving round the Sun, the planetary motions must necessarily appear very complicated. To explain the fact that the planet's apparent motion is sometimes from east to west, sometimes from west to east, and sometimes ceases altogether, we have only to consider the different relative positions of the Sun, the Earth, and the planet.

55 Let us suppose the planet to be what is called *inferior*—i. e., nearer to the Sun than the Earth is, of which kind there are two, Mercury and Venus. In this case the motion of the planet about the Sun will be quicker than that of the Earth, for the nearer a planet is to the Sun, the faster it moves. In the first place, suppose the three bodies to be in the positions represented in fig. *j*, E denoting the Earth, S the Sun, and P the planet—say Venus, for example. The arrows show the directions in

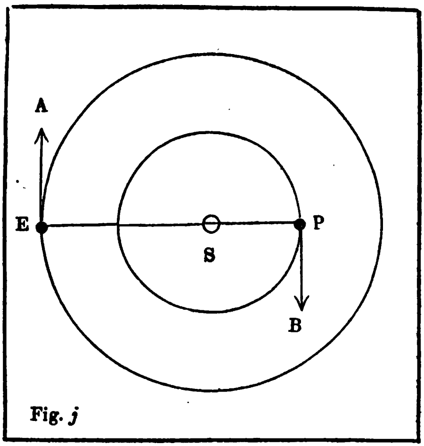

Fig. *j*

which E and P are moving in the circular orbits about S. While P is moving over a space of 10 miles along its orbit, E will describe a space of about 8½ miles, for the velocity of the Earth is, in round numbers, to that of Venus, as 8½ is to 10.

Now the effect of the Earth's motion of 8½ miles, will be to produce an apparent motion in Venus of 8½ miles, but in the opposite direction to that of the Earth*—i. e., in the direction of the arrow B. This apparent motion must therefore be added to the real motion of Venus—namely, 10 miles—which gives altogether a motion, in the direction B, of 18½ miles.

56 Secondly, suppose the three bodies to be in the positions represented in fig. *k*, then the motion of the Earth will, as before, communicate an apparent motion of 8½ miles to P, but now in the contrary direction to the arrow B, which shows the direction in which Venus describes her real motion of 10 miles. The apparent motion must therefore now be subtracted from the real motion, and this will leave altogether a motion of 1½ miles in the direction B.

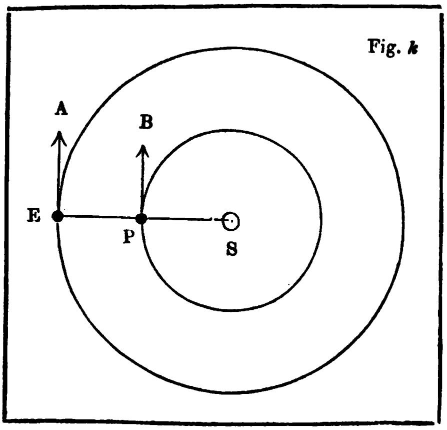
Fig. *k*

57 Hence, to a spectator on the Earth, Venus, when situated as in fig. *j* with respect to the Earth and Sun, will appear to move with almost double her real velocity, from west to east, for that is evidently the direction in which B points in fig. *j*, being the direction in which the Sun will appear to move, in consequence of the Earth's motion about him. But when situated as in fig. *k*, Venus will appear to move, with not one-fifth of her real velocity, in the opposite to the former direction, that is, she will appear to move from east to west.

58 Thirdly, when the three bodies are situated as in fig. *l*, the real motion of Venus will be oblique to the line E P, and so will the apparent motion which arises from the Earth's real motion, and is equal and opposite to it. But the former motion will be more oblique than the latter, and therefore the former motion, which is the greater of the two, will appear more diminished in consequence of the obliquity of the line E P, than the latter, so much so, that supposing E and P to be in the proper relative positions in their orbits, the two motions will appear to counteract each other, and the planet will then seem to be stationary.

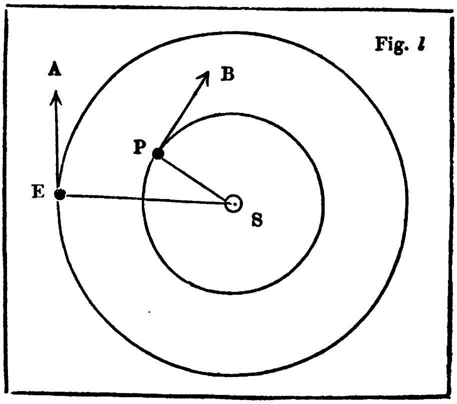
Fig. *l*

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* A spectator in smooth and rapid motion, as for instance in a railway carriage, becomes insensible of his own motion, and fancies that external objects, trees, buildings, &c. are all moving backwards at the same rate that he is really moving forwards.

59 Thus it is evident that the Copernican hypothesis (that the planets, with the Earth, move round the Sun as centre) clearly explains the otherwise unaccountable fact of the planets sometimes appearing to move from west to east, sometimes from east to west, and sometimes to be stationary.

60 The same reasoning as the above would apply to the *superior* planets, or those farther than the Earth from the Sun, of which the principal are Mars, Jupiter, Saturn, Uranus, and the lately discovered Neptune. Only a slight difference must be made because of their real motions being always greater than the apparent motion produced in them by the real motion of the Earth.

61 We have now given a sufficient general statement of the principal celestial motions, to serve as an introduction to the subject of astronomy. In the following chapters we shall confine our attention to the practical part of astronomy, as far as it is important to our present purpose, and space will permit.

CHAPTER II.

THE CELESTIAL SPHERE AND ITS CIRCLES. THE CONSTELLATIONS.

I. *Importance of a knowledge of the Constellations.*

A KNOWLEDGE of the manner in which the stars are grouped together and distributed over the heavens, and some degree of familiarity with the names and positions of the different constellations, and of the principal stars composing them, are highly desirable, not only as matters of deep interest, but also of practical importance. It is true, indeed, that an astronomer in his observatory may make his observations without ever having looked upon the heavens with the naked eye, he may, by means of his catalogues, his tables, and his clock, point his telescope to any particular heavenly body without looking out for it beforehand; and so far the knowledge we speak of is of no importance to him. But, if he wishes to compare his observations with those of others in past times, and to study the records of astronomers, both ancient and modern, he must be perfectly familiar with the classification of the stars into constellations which has prevailed over the whole civilized world for centuries, and which has the sanction of every great astronomer since the earliest times.

63 But there are very few who have an observatory to make use of; the great majority of persons who study astronomy practically must make their observations with portable instruments, in unknown latitudes; indeed, the object such persons have in view is to determine where they are on the Earth's surface, and it is chiefly for this purpose that they study astronomy. Now to such persons, catalogues and tables can be of no use, as far as finding any particular star is concerned; for an astronomer cannot point his telescope by such means except he knows his exact position on the Earth's surface. A sailor who wishes to direct his course over the ocean by astronomical observations, must know where to look for each heavenly body he makes use of for that purpose; and the same is true of every observer in an unknown locality; he must be perfectly familiar with the different groups of stars, the names they are called by, and their relative positions in the heavens; otherwise, however well versed he may be in the theory of astronomy, he will not be able to make any use of it practically.

64 But it may be said that the classification of the stars which has been so long in use, is perfectly arbitrary, having no absolute relation to their actual distribution and arrangement; that a much better, and less absurd system of

grouping might be adopted than the monsters and figures of the celestial globe. This may be true, to a certain extent, but exactly the same thing might be said of the division of England into counties. If any one proposed to make a new and more convenient division of England, by forming it into squares, or rectangles, or any other regular figures, it would be easy to show the uselessness and inconvenience of such a proposition, by saying that the present division into counties has been in existence for a long period of time, that it is recognised in our laws, our historical records, and our literature, and that it is in many cases well suited to the natural divisions of the country. We may make a similar answer to any one objecting to the present division of the heavens into constellations. It has been in existence for centuries. Astronomers have always made use of it in describing celestial phenomena, and in recording their observations; and ancient writers are full of allusions to it, not only astronomical and geographical writers, but poets, historians, chronologers, and even the writers of the inspired volume. Besides, the division is by no means unsuitable to the actual grouping of the stars, and makes a much more lasting impression on the memory than a more regular division, as, for example, into zones and segments of zones, would do.

65 To the geographical student, a perfect acquaintance with the constellations is absolutely necessary, if he wishes to make any practical progress in the scientific part of the subject. We shall therefore devote the present chapter to this part of astronomy, and endeavour to give a fair general idea of the manner in which different constellations are distributed over the heavens, and the positions of the principal stars composing them.

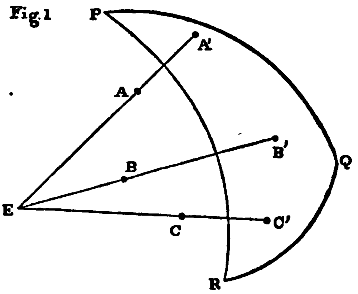
II. *Preliminary Observations respecting the Celestial Sphere and its Circles.*

66 Before we proceed to the description of the constellations, we must first say a few words respecting the celestial sphere and its circles, as we shall have to refer to these points constantly in all that we say respecting the constellations.

67 *Celestial Sphere.*—A sphere is the surface in solid geometry, which corresponds to the circle in plane geometry. Every point of a spherical surface is equally distant from the centre, and every part of the surface has the same degree of curvature. The distance of any point on the surface of a sphere from the centre is called the radius of the sphere, in the same manner as in the circle.

The Celestial Sphere is a sphere described about the eye of the observer as centre, with a radius of very great length. On the surface of this sphere all the heavenly bodies are *projected*, by lines drawn from the eye—that is to say, if P Q R be supposed to represent a portion of the spherical surface, E, the eye of the observer—i. e., the centre, and A B C any heavenly bodies at different distances from E; then, if lines be drawn from E through A B and C, to meet the spherical surface at the points A′ B′ C′, these points are said to be the *projections* of the heavenly bodies A B C *upon* the spherical surface, and the heavenly bodies are said to be *projected by* these lines *upon* the spherical surface.

Fig. 1



68 In point of fact, the heavenly bodies are so far off that the eye cannot appreciate their different distances, and they appear as if they were all at the same distance from it—i. e., we view them as if they were all projected on a sphere of immense extent, described round the eye as centre.

69 It is very convenient to make use of an imaginary sphere as a means

of representing the apparent positions of the heavenly bodies. The common celestial globe is intended to exhibit this sphere in miniature, with the various stars and constellations placed upon it, as they actually appear to the eye to be placed in the heavens.

70 It is important to explain for what reason we suppose the radius of the celestial sphere to be of immense length. It is not merely because it appears to be so, but because, by such a supposition, we avoid the necessity of defining very exactly the position of its centre. It would be very inconvenient if we considered this sphere to be described with a radius equal to the Moon's distance from us, great as that distance is; for then a change of the observer's position would sensibly alter the position of the celestial sphere. Even the Sun's distance, and we may, in the present perfection of astronomical science, say, even the distance of the nearest fixed star, would be too short a radius for our purpose. As this is a point of considerable importance, especially as it relates to what is called *Parallax,* we must endeavour to make our meaning clear by means of a figure.

71 Let A and B, (figs. 2 and 3,) be two centres, about which two circles of equal radius are described. The distance between A and B, in fig. 3, is the same as in fig. 2, but the radius of the circles in fig. 3 is much longer than in fig. 2. It is easy to see, by a simple inspection of the two figures, that the two circles in fig. 3 are much more nearly coincident with each other than the two circles in fig. 2. This is made more manifest by fig. 4, which represents the two circles in fig. 2 magnified so much as to become the same size as the circles in fig. 3.

Fig.2

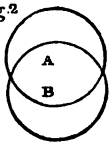


Fig. 3

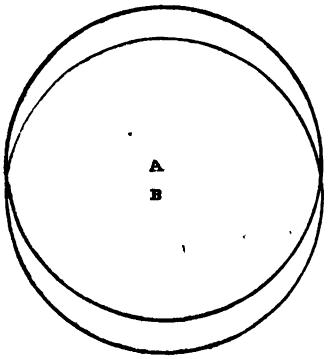
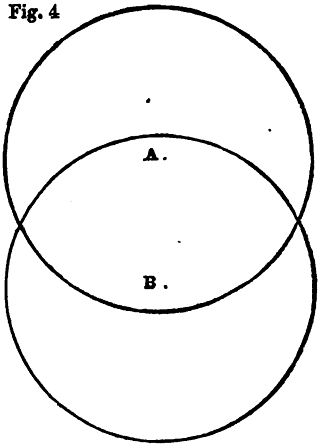


Fig. 4



72 Now, we may suppose A and B to be the positions of two observers on the Earth's surface, and the two circles to represent celestial spheres described about A and B as centres. If the radius with which the spheres are described be so small (compared with the distance of A from B) as is represented in fig. 2, it is clear that the observer at B will employ a celestial sphere sensibly different in position from that employed by the observer at A. But if the radius of the spheres be as large (compared with the distance of A from B) as is represented in fig. 3, then the two spheres will not differ, as regards their position, in anything like the same degree as in the former case.

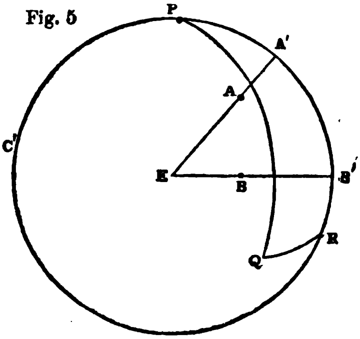
If we had space on this paper to represent two spheres described with a radius immensely exceeding the distance between the centres A and B, it is easy to conceive, by comparing figs. 3 and 4, how little the two spheres would differ from each other in position.

73 Hence the importance of supposing the radius of the celestial sphere to be very great, compared with the greatest distance at which two places of observation on the Earth's surface may be from each other; for then we may suppose that the celestial sphere at both places is the same both in magnitude and position, at least, we may consider the change of position of the celestial sphere, in consequence of the observer's change of place, to be practically insensible, compared with the magnitude of the sphere. We may, in fact, assume, without any error worth taking into account, that observers at different places on the Earth's surface, however distant from each other, project the heavenly bodies on the same celestial sphere.

We must remember that, in consequence of the Earth's motion round the Sun, an observer changes his place in every half year, by a distance of 190 millions of miles, in round numbers. Therefore, we must consider the radius of the celestial sphere to be immensely greater than 190 millions of miles. The simplest thing to say on the subject is this—that the imaginary celestial sphere is of such enormous dimensions, that the whole space occupied by the solar system is a mere point compared with it, just as the hole made by the point of a compass in describing a large circle on paper is considered as a mere point, though in reality it is of sensible magnitude, and might be made to appear large enough if magnified.

74 *Circles of the Celestial Sphere.*—Circles described on the celestial sphere, with the observer's eye as centre, are employed very conveniently to measure the angles, made by lines drawn from the observer's eye, in the following manner:—

Fig. 5

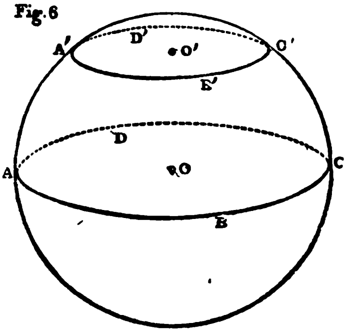


Let E, fig. 5, be the observer's eye, P Q R a portion of the celestial sphere, A and B two heavenly bodies, which are projected upon the celestial sphere by the lines E A and E B, which meet the sphere at A' and B'. With E as centre, describe on the sphere a circle, A' B' C', passing through the points A' and B', and divide the whole circumference of this circle into 360 equal parts or *degrees.* Then, if the portion A' B' of its circumference contains 10 of these equal parts, it is clear that the angle A' E B' is an angle of 10 degrees; if it contains 20 of the equal parts, A' E B' will be an angle of 20 degrees, and so on. If, therefore, we conceive every circle described on the spherical surface about the eye as centre, to be divided into 360 equal parts, each of these parts into 60 equal subdivisions, or *minutes*, and each subdivision into 60 equal subdivisions, or *seconds*, again; these divisions and subdivisions will show how many degrees, minutes, and seconds there are in the angle contained by any two lines drawn from the eye. By producing the two lines to meet the sphere, and then connecting the points of meeting by a circular arc, described about the eye as centre, the divisions and subdivisions of this arc will show how many degrees, minutes, and seconds there are in the angle made by the two lines.

75 This method of exhibiting the angles, which lines drawn from the eye make with each other, by means of circular arcs described on the surface of the celestial sphere, is very convenient, as it greatly helps the mind to understand and make out how such angles are related to each other. This is the foundation of what is called *Spherical Trigonometry*, of which we shall speak more hereafter.

76 *Small and Great Circles of the Sphere.*—The circles we have just spoken of are called *Great Circles of the Sphere*, the distinguishing property of which is—that they are described about the centre of the sphere (i. e., the

Fig. 6



eye) as centre. A circle described on the sphere, about any other point as centre, is called a *Small Circle*.

It is easy to see that a great circle divides the spherical surface into two equal parts (which are therefore called *Hemispheres*); but a small circle divides it into two unequal parts.

In fig. 6, A B C D shows a great circle, and A′ B′ C′ D′ a small circle of the sphere, the centre of the former circle being O, which is supposed to be the centre of the sphere, and the centre of the latter being O′, which does not coincide with the centre of the sphere.

77 If we make a section of a sphere by a plane, the section will be circular. If the centre of the sphere be in the cutting plane, the section will be a great circle, as is shown in fig. 7; if not, it will be a small circle, as is shown in fig. 8; A B C D showing the cutting plane, and O the centre, in both figures.

Fig. 7

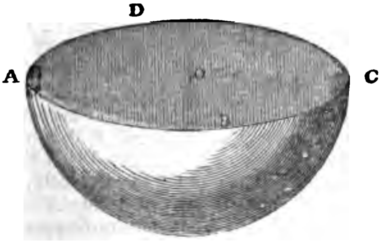
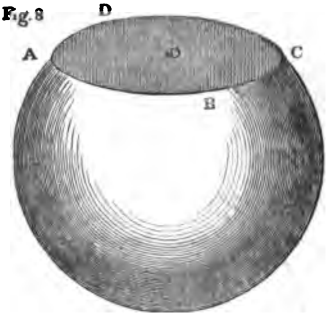
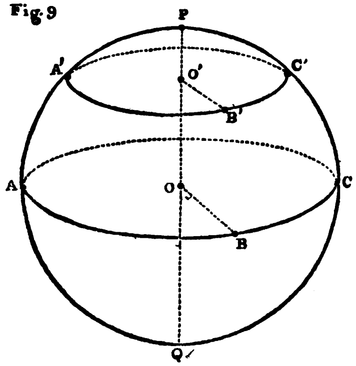


Fig. 8



78 We may therefore define a great circle to be the section resulting from cutting the sphere into two equal parts by a plane, and a small circle to be the result of cutting it into two unequal parts.

Fig. 9



79 *Pole of a Circle of the Sphere.*—Let O, fig. 9, be the centre of the sphere; draw any line P Q through O to meet the surface of the sphere at the points P and Q; and let O B be a line drawn from the centre O, perpendicular to the line P Q, to meet the spherical surface at the point B.

Now suppose P and Q to be two points, or pivots, about which the line P Q may turn, carrying the line O B with it; in fact, let P Q be an axis, and O B a perpendicular rod firmly attached to it. Then, if this axis be turned round, it is clear that the extremity B of the rod O B will trace a circle C B A on the spherical surface, which circle, since its centre is evidently at O, is a great circle.

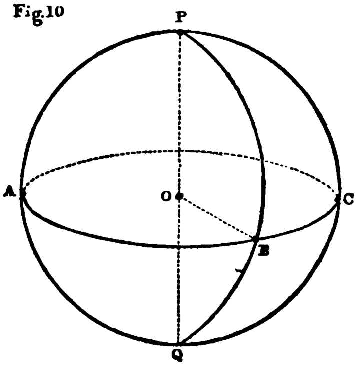
80 If O′ B′ be another line, or rod, perpendicular to the axis P Q and firmly fixed to it, and if B′ be the point where it meets the spherical surface, then the point B′ will trace out another circle, C′ B′ A′, when the axis is

turned round about its pivots P and Q; and this circle will be a small circle, because its centre, O′, does not coincide with the centre of the sphere.

81 P and Q are called the *Poles* of these circles; the word Pole being derived from the Greek, which signifies a hinge, pivot, or bearing, about which a body may smoothly turn.

82 All circles described about the same poles are called *Parallel Circles*, or *Parallels*, because they are at all points equidistant from each other. Thus the two circles, C B A and C′ B′ A′, being described about the same poles, P and Q, in the manner above described, are parallel circles. An infinite number of circles parallel to C B A, may be described by assuming the point O′ in different positions along the axis P Q.

Fig.10

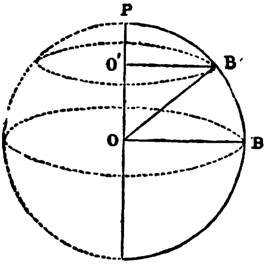


Every point *of a great circle* is 90 degrees from its pole; for if B (fig. 10) be any point of the great circle C B A, and if we draw another great circle P B Q, connecting the points P B and Q, it is clear that P B Q is a semicircle, and therefore measures 180°, and, since B is half way between P and Q, P B and Q B must each measure 90°.

Every point of a small circle is less than 90° from one pole, and more than 90° from another pole.

83 *Comparative Magnitudes of Small and Great Circles.*—Let P B Q (fig. 11) be a semicircle, P Q its diameter, O its centre, O B and O′ B′ lines perpendicular to P Q. Then if we conceive this semicircle to be turned about P Q as an axis, P and Q being the pivots or poles, the semi-circumference P B Q will evidently describe, or, as it is said, *sweep out* a spherical surface, the point B will describe a great circle, and the point B′ a small circle, O and O′ being the respective centres of the two circles. Our object is to compare the magnitudes of these two circles.

Fig 11



Now it is well known, that the greater the radius of a circle is, the greater is the circumference in proportion; if the radius of one circle be twice that of another, the circumference of the former will be twice as long as that of the latter; if three times, three times; if four times, four times, and so on. Hence, whatever be the proportion of O′ B′ to O B, the same will be the proportion of the small circle (which is described with O′ B′ as radius) to the great circle (which is described with O B as radius.)

The circular arc P B′ shows the distance of every point of the small circle from its pole P; if P B′ contain 10°, or 20°, or 30°, the small circle is accordingly said to be 10°, or 20°, or 30° from the pole. P B′ is commonly called the *Polar Distance* of the small circle.

84 The fraction which O′ B′ is of O B, is called in trigonometry the *sine* of the circular arc P B′; thus, if O′ B′ be ½ of O B, the sine of P B′ is said to be ½; if O′ B′ be ⅓ of O B, the sine of P B′ is said to be ⅓, and so on. Tables are calculated, by which the sines of arcs of every magnitude, from 0° to 90°, may be found immediately; so that by simple inspection of these tables we may find what fraction O′ B′ is of O B, if the number of degrees in P B′ be given

85 Now, whatever fraction O′ B′ is of O B, the same fraction is the small circle described about O′ as centre of the great circle described about O as

centre. Hence we have the following rule for finding what fraction the former circle is of the latter.

To find what fraction the circumference of a small circle of the sphere is of a great circle, look in a table of sines for the sine of the polar distance of the small circle, and that will be the fraction required.

If the length of the great circle be given, that of the small circle is found by multiplying the length of the great circle by the proper fraction—i. e. by the sine of the polar distance of the small circle.

86 The following short table shows the sines of circular arcs for every five degrees, from 0° to 90°:—

Circular Arc.	Sine.	Circular Arc.	Sine.	Circular Arc.	Sine	Circular Arc.	Sine.
0	0	25°	$\frac{423}{1000}$	50°	$\frac{766}{1000}$	75°	$\frac{966}{1000}$
5°	$\frac{87}{1000}$	30°	$\frac{500}{1000}$	55°	$\frac{819}{1000}$	80°	$\frac{985}{1000}$
10°	$\frac{174}{1000}$	35°	$\frac{574}{1000}$	60°	$\frac{866}{1000}$	85°	$\frac{996}{1000}$
15°	$\frac{259}{1000}$	40°	$\frac{643}{1000}$	65°	$\frac{906}{1000}$	90°	1
20°	$\frac{342}{1000}$	45°	$\frac{707}{1000}$	70°	$\frac{940}{1000}$		

87 If we suppose the small circle, like the large circle, to be divided into 360°, a degree of the small circle will be the same fraction of a degree of the large circle that the whole circumference of the small circle is of the whole circumference of the great circle. Hence the length of a degree of a small circle is to be found by multiplying the length of a degree of a great circle by the sine of the polar distance of the small circle.

Thus, if we suppose a small circle described on the Earth's surface at 40° from the north pole (which is the polar distance of the southern extremity of England), the circumference of that circle will be (the sine of 40° being $\frac{643}{1000}$) $\frac{643}{1000}$ of the whole length of the equator; and the length of a degree of this small circle will be got by multiplying 69½ miles (the length of a degree of the equator in round numbers) by $\frac{643}{1000}$.

Having dwelt sufficiently on these points, we shall now go on to describe the appearance and arrangement of the stars on the celestial sphere.

III. *Classification of the Stars with respect to Brightness.*

88 The apparent brightness of the stars is very different; some shine with considerable brilliancy, some are less bright, others almost invisible to the naked eye, and multitudes to be seen only by the aid of the telescope. As the apparent brightness of a star is, to a certain extent, a distinguishing mark of it, it is important to have some classification of the stars with respect to the quantity of light they emit to the eye.

89 Stars visible to the naked eye are divided into six classes; those of the first class are the brightest, and are about twenty in number: they are called stars of the *first magnitude*. The second class includes about seventy stars which, though clear and bright, are not so remarkable as those in the first class; they are called stars of the *second magnitude*. The third class consists of about 220 stars, fainter, of course, than the former, but still very obvious to the eye; these are said to be of the *third magnitude*. There are about 500 stars of the *fourth magnitude*, 690 of the *fifth*, and 1500 of the *sixth*. The stars of the fifth and sixth magnitude are not visible on a clear moonlight night to the naked eye, and therefore on such a night those of the fourth magnitude will be the faintest visible without telescopic aid. Altogether, there are, in round numbers, about three thousand stars that are visible to the naked eye.

90 Stars which can be seen only through a telescope are called *telescopic* stars. They are spread over the whole expanse of heaven, in some places close together, as in the Milky Way, in other places far apart. Where they are close together, they are seen by the naked eye like cloudy spots or streaks in the heavens, which, when examined by a powerful telescope, completely change their appearance, and become assemblages of innumerable bright points of light sprinkled, as it were, over a dark ground. The Milky Way, which appears like a faint, narrow cloud of irregular shape encircling the whole celestial sphere, is well known. Besides this, there are a number of small cloudy spots of various shapes called Nebulæ seen by means of a telescope of moderate power, many of which, on using a higher power, are resolved, as it is said, into assemblages of stars. Some of them have never been resolved even by the magnificent instrument of Lord Rosse, seen through which they still present the same indistinct and hazy appearance as in a less powerful telescope.

91 The classification of the stars visible to the naked eye into six classes or magnitudes is very convenient in a general way; but for accurate purposes it is too rough, and subject to great uncertainty; so much so that many stars, which are considered in some maps as of one magnitude, are in other maps put down as of a different magnitude. Thus, for instance, in Littrow's maps (Atlas des gestirnter Himmels) the seven stars in the Great Bear are represented to be all of the second magnitude, except the star marked δ, which is put down as of the third. But in the maps published by the Society for the Diffusion of Useful Knowledge, the star a is considered to be of the first magnitude, β, γ, and η of the second, and δ, ϵ, ζ of the third.

92 There is, however, a good reason for uncertainty with respect to the magnitudes of several stars, in the fact that they appear to change their magnitude from time to time, being subject, from some cause or other, to a periodical variation of brightness. Thus, for example, the remarkable star *Algol* (β Persei) suffers a considerable change of brightness in a period of not quite three days, being at one time during that period of the second magnitude, and at another time only of the fourth.

93 The most probable way of accounting for this change of brightness is by the supposition that it is caused by the revolution of spots on the star's disk, as in the case of the Sun, or by large planetary bodies moving round the star as their Sun. The manner in which the brightness of Algol varies makes this very likely, for it changes rapidly from the second to the fourth magnitude, and then as rapidly back again to the second, after which it remains unchanged for the remainder of the period. The change from the second magnitude to the fourth and back again occupies only seven hours; while the time during which the star retains its brightness unchanged is about sixty-two hours. This is accounted for easily, if we suppose a spot or opaque body to revolve round the star in about sixty-nine hours, during seven hours of which time it is between the eye and the star.

For full information respecting this interesting point, we may refer the reader to Captain Smyth's *Celestial Cycle*, in the second volume of which complete and accurate information is given respecting almost every star and object of interest in the heavens. This is a most valuable, and we may say amusing book, and ought to be in the hands of every one who takes an interest in astronomy.

94 A good method of getting an idea of the magnitudes of the different stars is to watch them as they become visible in succession after sunset. As the daylight fades away, those of the first magnitude are seen first; soon after, those of the second come out, then those of the third, and so on. The light of the Moon may also be used as a test of the comparative brightness of the stars. For more accurate methods, *see* Smyth's *Celestial Cycle*, vol. i. p. 272.

It is scarcely necessary to observe that the word magnitude, as applied to the stars, is not used in its proper signification; it has, of course, no reference to the real magnitudes or dimensions of the stars, but only to their apparent brightness.

95 We shall now proceed to describe the principal constellations, and show how and where they are to be found in the heavens. As we go on, we shall explain the meaning of various astronomical terms which have relation to the celestial sphere, and to the apparent motion of the Sun.

In describing the constellations, we shall endeavour to do so in such order, and to classify them in such a manner, that any one may, in a short time, make himself quite familiar with their appearance and relative positions in the heavens.

IV. *Of the North Circumpolar Region of the Heavens.*

96 *Method of finding the Pole Star by means of the Great Bear.*—If we observe the motion of the stars for four or five hours, we shall perceive, as has been already stated, that they all revolve about a particular point of the heavens, which is called (in these latitudes) the North Pole. Near this point is a tolerably bright star, which is known by the name of the *Pole Star.* There is no other star of equal brightness in the immediate vicinity of the North Pole, and therefore the Pole Star, once pointed out, is easily recognised again, especially as it is always to be seen in the same direction on account of its nearness to the Pole; for the circle it describes about the Pole is so small, that its motion is not sensible to the eye without the assistance of some instrument.

97 To find the Pole Star, we must have recourse to the remarkable and well-known group of stars commonly known by the name of the Great Bear, of which imaginary animal they form the tail and hind quarter. They are often called Charles' Wain, and sometimes the Plough, and this latter name gives the best idea of the form of this group of stars.

Their Latin name was Septem Triones, or the Seven Oxen; Trio signifying an Ox. The Greek name, *αρκτος,* (*arctos,*) signifies a bear, and hence the northern region of the heavens is called the *Arctic* region. The Latin name of the whole constellation of the Great Bear is Ursa Major.

The group consists of seven rather bright stars, which are usually denoted by the Greek letters, *α β γ δ ε ζ η*, as is shown in fig. 12. The three stars, *ε ζ η*, form the tail of the Great Bear, *α β γ* and *δ* the hind quarter. The whole constellation, with the imaginary figure of the Bear, is shown in fig. 13, (on next page,) which includes all the stars as far as the fourth magnitude.

98 The star *α* is called *Dubhe,* (an Arabic name, signifying the Bear;) it is the brightest star of the seven, and may be considered as of the first magnitude.

The star *δ* is the faintest of

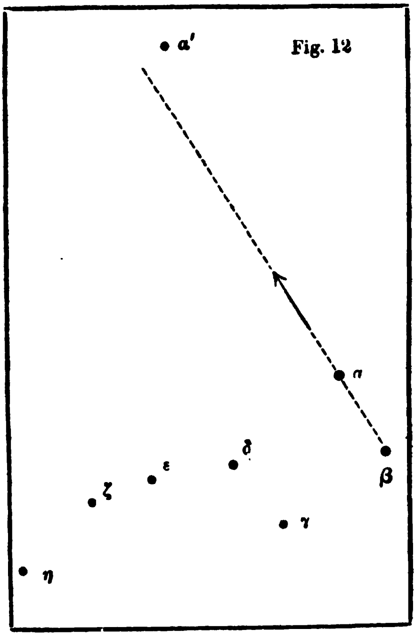
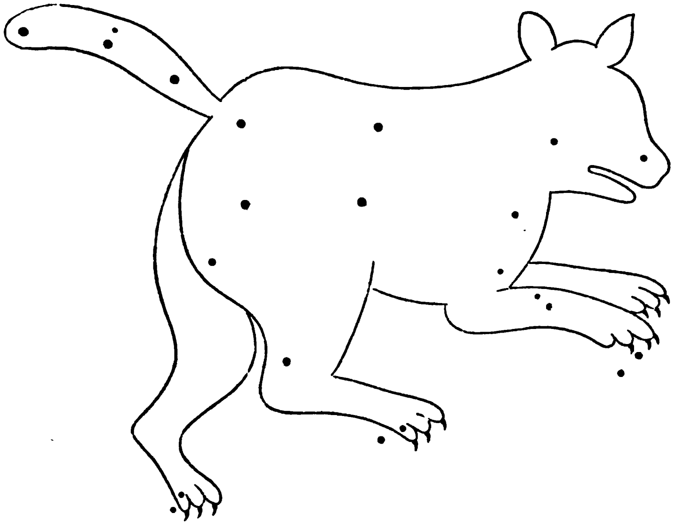


Fig. 12

Fig. 13



the group, and is of the third magnitude; the other stars may be considered as of the second magnitude.

This constellation is constantly alluded to by ancient writers. In Homer (*Od.* v. 272) we find the following lines:—

> *οὐδέ οἱ ὕπνος ἐπὶ βλεφάροσι ἔπιπτεν*
> *Πληϊάδας τ' ἐσορῶντι καὶ ὀψὲ δύοντα Βοώτην*
> *Ἄρκτον θ' ἣν καὶ Ἄμαξαν ἐπίκλησιν καλέουσιν*
> *ἥτ' αὐτοῦ στρέφεται καὶ τ' Ὠρίωνα δοκεύει*
> *οἴη δ' ἄμμορός εστι λοετρῶν Ὠκεανοῖο.*

'Nor did sleep fall upon his eyelids as he watched the Pleiades, and the late-setting Bootes, and the Bear, which also is commonly called the Wain, which revolves in that part of the heavens, and watches Orion, and alone is never bathed in the ocean.'

99 The stars α and β are commonly called the ***Pointers***, because they point nearly towards the Pole Star. If an imaginary line be drawn in the heavens through the Pointers, it will pass near the Pole Star, as is represented in fig. 12, where α' denotes the Pole Star.

In finding the Pole Star by means of the Pointers, it is important to remember that this line is to be drawn in the direction represented by the arrow, i. e., from β to α, not from α to β. From α' to α is about five times the distance between α and β, α' is on the *off side* of the line of direction of the Pointers, with reference to the seven stars, i. e., ***not*** on the same side as the tail. We may therefore give the following rule for finding the Pole Star:—

100 Draw an imaginary line in the heavens from β to α, and produce it on till the produced part is about five times the length of the distance from β to α; then near the extremity of this line, on the contrary side to the Bear's tail, will be seen a star, with no other equally bright in its vicinity, which is the Pole Star.

101 *Of the Little Bear, or Ursa Minor.*—The Pole Star, or ***Polaris***, as it is often called, forms the extremity of the tail of what is known by the

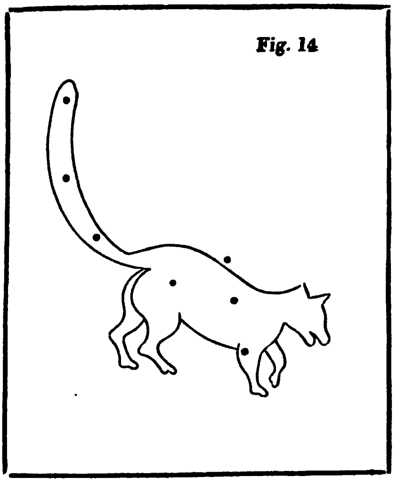


Fig. 14

name of the *Little Bear*. This constellation is by no means so obvious to the eye as the seven stars of the Great Bear, the stars composing it being fainter, with the exception of Polaris. The Little Bear is represented in fig. 14, with the form of the animal traced out. The relative positions of the Great Bear and Little Bear are shown in fig. 15.

The stars of the Little Bear form a figure not unlike that of the seven stars of the Great Bear. It may be well to observe, that the tails of the two Bears are on contrary sides. The stars of the Little Bear are denoted by Greek letters, as is represented in fig. 15, and the same plan is adopted in all the other constellations. The Pole Star is α of the Little Bear, and in most cases α denotes the brightest star of a constellation. It is usual to specify any particular star by prefixing the Greek letter by which it is denoted to the Latin name of the constellation to which it belongs in the genitive case. Thus, Polaris is spoken of as α Ursæ Minoris, β of the Great Bear as β Ursæ Majoris, and so on. Sometimes stars are marked by Roman letters and by numbers; for instance, we have 61 Cygni, m Ursæ Majoris.

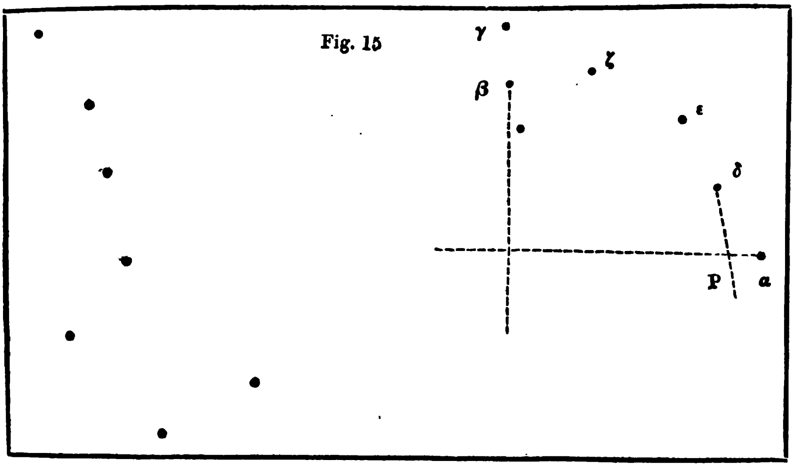


Fig. 15

102 The use which was made of Polaris in navigation is well known, and is very ancient. Polaris is often called the *Lode Star*—i. e., the leading or guiding star. It was formerly called *Cynosura*, or the *Dog's Tail*, Ursa Minor having been figured as a dog in those times.

The word cynosure has passed into our language, denoting whatever is a centre of attraction to the eye: thus, in Milton's *L'Allegro* we have—

> Where perhaps some beauty lies,
> The Cynosure of neighbouring eyes.

In the Latin translation of the poem of Aratus we have—

> Ex his altera apud Graios Cynosura vocatur
> . . . .
> Hac fidunt duce nocturna Phœnices in alto.

Probably this line explains why Polaris was often called Phœnice.

103 The two stars β and γ of the Little Bear were called the *Guards*, from a Spanish word signifying 'to watch,' because they were used by sailors to mark the hour of the night before watches and chronometers were invented. The star β was nearer to the pole than Polaris two thousand years ago, and it was the North Star of the Arabian astronomers, whence it was called *Kocab*.

104 The position of the pole may be nearly found by means of the Pole Star and the Guards, in the following manner:—

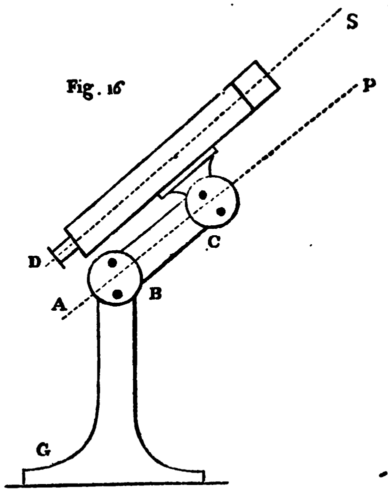
In fig. 15, draw a line through Polaris (*a*) perpendicular to the line joining the two Guards β and γ, and in that line, about 1½° from Polaris, is the North Pole, represented by P in the figure.

105 To get an idea of the distance of the Pole from Polaris, we may observe that the Pole is about twice as far from the star δ as it is from *a*, and that the line drawn from δ to P is inclined, as is represented in the figure, to the line drawn from *a* perpendicular to that passing through β and γ.

At present the Pole is getting nearer to the Pole Star; in about 140 years the Pole will be about ½° from Polaris, afterwards it will recede from it.

106 *Method of Setting the Instrument described in the former Chapter.*—We shall here explain the manner in which the instrument, described in the former chapter, may be placed with the axis A P (fig. *e*) pointing towards the Pole nearly.

Fig. 16



First, the telescope (or the rod with sights) must be turned round its pivot C, until it points in the same direction as the line A P, as is represented in fig. 16. This may be easily done by pointing the telescope, placed as in fig. 16, towards any distant object, S, and then turning the tube B C round. If, on doing this, the object S does not appear to change its position in the telescope, then it is easy to see that the line D S must be parallel to the axis A P, about which the tube has turned. If, however, the object S appears to change, the telescope must be slightly turned about its pivot C, until the apparent position of the object S, in the telescope, is not affected by the motion of the tube about its axis.

107 When the telescope is thus adjusted, the graduated circle, which is attached to C, to measure the angle made by the lines A P and D S, ought to show zero, since the two lines are then parallel. This gives us a method of finding whether the graduated circle is properly placed or not, and if not, of making the necessary adjustment.

108 Now, supposing the telescope to be placed with its line of collimation, D S, parallel to the axis A P, let the whole upper portion of the instrument be turned about the joint A, and the vertical stem A G also if necessary, until the telescope points to the Pole, the position of which must be guessed by the eye, by drawing from Polaris an imaginary line, perpendicular, as nearly as can be judged, to the line joining the two Guards, and taking a point on that line twice as far from the Star δ as from Polaris. This may

be easily done without losing more than a half of a degree from the true place of the Pole, and this will be sufficiently accurate, considering the rudeness of the instrument. The axis A P, having been once directed to the Pole, should be fixed in that position, which may be done by tightening the joint A, and by putting three marks on the circumference of the base of the instrument G, and three corresponding marks on the pedestal out of doors upon which the instrument is placed, so that the instrument may be put back in its proper place, should it have been removed.*

109 With the instrument thus placed, the general facts stated in the former chapter, respecting the circumpolar motion, and the proper motions of the Sun, Moon, and Planets, may be easily observed according to the method described in the case of the Sun.

110 *Cassiopea's Chair.*—If an imaginary line be drawn from any one of the three stars forming the tail of the Great Bear (ϵ, ζ, or η, Ursæ Majoris) through Polaris, it will lead to the constellation *Cassiopea*, the five principal stars of which form Cassiopea's Chair, which is something like a distorted M or W. The Pole is about half-way between the tail of the Great Bear and Cassiopea's Chair. Fig. 17 shows the five principal stars of this constellation.

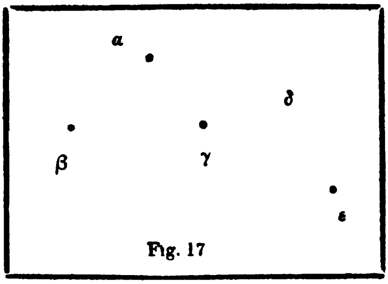
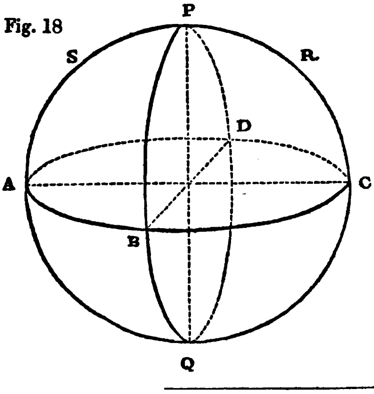


Fig. 17

111 It is worth remembering, that the five stars of the Chair form two triangles, one nearly a right angled triangle, consisting of α, β, and γ, and the other a very obtuse angled triangle, consisting of γ, δ, and ϵ. We make this observation, because, without it, it is not easy to distinguish β from ϵ, and it is of some importance to remember which of the five stars is β.

112 β Cassiopeæ is a star of the second magnitude, and is the extreme, on the side of the right angled triangle, of the five stars. If a great circle be drawn through Polaris and β Cassiopeæ, it coincides very nearly with the great circle called the *Equinoctial Colure*—i. e., the great circle passing through the poles and the two equinoctial points of the Equator. All great circles passing through the Poles were formerly called Colures, (κόλουροι,) because, as the word signifies, they were partly cut off, or, as it were, maimed, by the horizon. The name is now restricted to *two* great circles passing through the Poles, one cutting the Equator at the equinoctial points, the other at points 90° from the equinoctial points. The former was called the Equinoctial Colure, the latter the Solstitial, because, as we have already explained, the points where the Sun becomes stationary for a short time (as far as his motion towards or from the Pole is concerned) are in the latter great circle.

Fig. 18



113 In fig. 18, which is supposed to represent a sphere, these circles are shown. A B C D represents the Equator, P the North Pole, Q the South Pole, A the Vernal Equinoctial point, C the Autumnal, B and D the points of the Equator which are 90° from A and C: then the great circle P A Q C is the Equinoctial Colure, and the great

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* A projecting piece at A, with a clamp and screw, would make it easy to point A P to the Pole, and keep it fixed at the proper inclination.

circle P B Q D the Solstitial Colure. The Equinoctial Colure is marked by the Stars δ Ursæ Majoris, Polaris, and β Cassiopeæ; the position of δ Ursæ Majoris is about at R, and that of β Cassiopeæ at S.

The star α of this constellation is one of those remarkable stars, the brightness of which is continually changing. α generally appears fainter than β, but sometimes it becomes brighter. What the cause of this change of splendour may be we can only guess. It is likely, as we have already stated, that there are spots on the star's disc, and that they sometimes appear and sometimes disappear, in consequence of the star's rotation about its axis, so causing a variation in the quantity of light emitted from the star; or the change of brightness may be caused by large planetary bodies revolving about the star as their sun, and sometimes intercepting the light of the star.

114 *The Dragon.*—The constellation *Draco*, the Dragon, commences between the Great Bear and the Little Bear, runs almost half way round the latter, and then turns off in the opposite direction. It is represented in fig. 19, with the form usually given to the Dragon traced out, Ursa Minor on one side of the tail, and the Septemtriones on the other. It is worth observing, that this constellation, commencing not far from α Ursæ Majoris, (the first of the Pointers,) lies on the *tail side* of the Septemtriones, and on the same side as the body, not the tail, of the Little Bear. In the 1*st Georgic* of Virgil, the position of Draco between the two Bears is described—

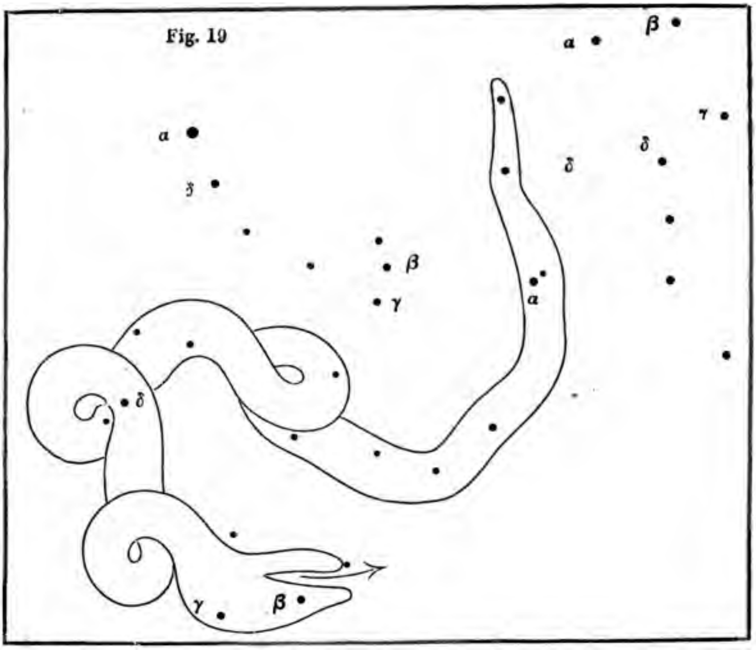


Fig. 19

Maximus hic flexu sinuoso elabitur Anguis
Circum perque duas in morem fluminis Arctos,
Arctos Oceani metuentes æquore tingi.

'Here the enormous Dragon glides round with winding flexure, like a river, between the two Bears, the Bears that fear to dip in the ocean.'

115 The star α Draconis, which is not far from half way between the two

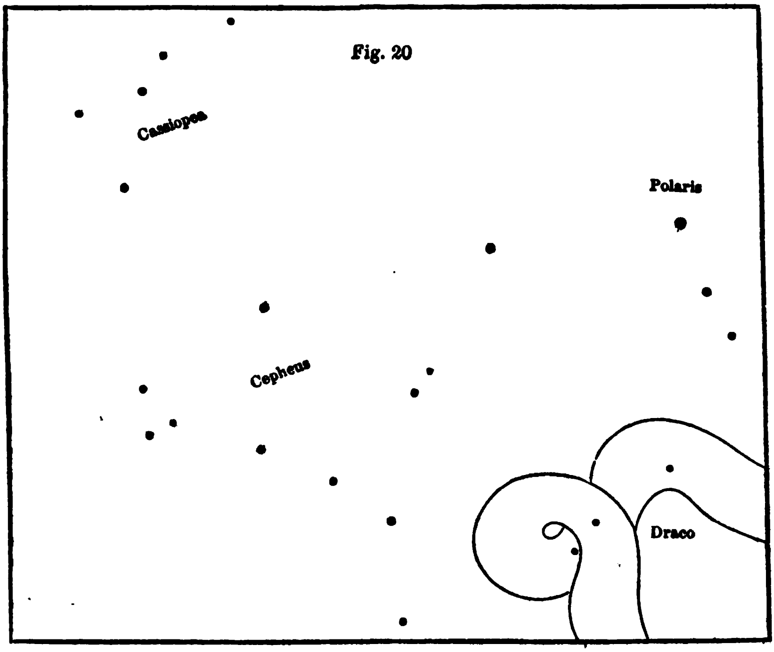
Guards in the Little Bear and the tail of the Great Bear, was formerly the Pole Star, the Pole having been very near it (not a quarter of a degree from it) in the times of the Chaldean observers.

116 The two principal stars of this constellation are those marked β and γ in the head of the Dragon, and their position should be well remembered; they are of the second magnitude. To find them, we have only to draw an imaginary line through α and δ Ursæ Minoris, near which they will be found, or, what is the same thing nearly, a line from Polaris, perpendicular to the line from Polaris to γ Ursæ Majoris, will find them. They are about at the same distance from the Pole as the second of the Pointers (β Ursæ Majoris). A line through the Guards (β and γ Ursæ Minoris), goes nearly through the head of Draco.

γ Draconis is a most remarkable star in the history of astronomy; it passes nearly vertically over Greenwich, and was on that account chosen by the great astronomer, Bradley, as the most suitable for his observations, which led him to the twofold discovery of the Aberration of Light and the Nutation of the Earth's axis.

117 *Cepheus.*—Between the Dragon and Cassiopea will be found the stars of this constellation; they are not easily distinguished from the stars of Draco, but, by remembering, that an imaginary line through γ Ursæ Majoris and β Ursæ Minoris, (the inner Guard,) separates Draco from Cepheus, there will never be any difficulty in making out the limits of Cepheus. Fig. 20 shows Cepheus.

Fig. 20

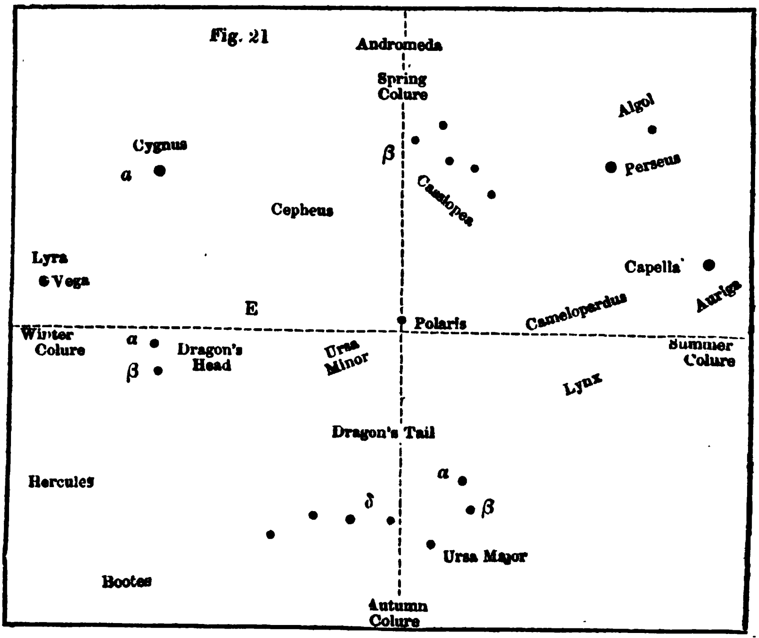


118 *Camelopardus.*—This constellation is by no means remarkable; it occupies the space on the opposite side of the Dragon beyond Polaris, and between the head of the Great Bear and Cassiopea.

119 *Position of the Colures with reference to the Circumpolar Stars.*—We have described the constellations in the immediate vicinity of the Pole at

some length, because, when their positions with reference to the Pole and to each other are well understood and remembered, they form so many guides and points of departure, whereby the other constellations may be readily found.

We have already stated that the Equinoctial Colure nearly coincides with the great circle passing through β Cassiopeæ, α Polaris, and between γ and δ Ursæ Majoris, nearer to δ than to γ. The *Solstitial Colure* runs through the Pole at right angles to the Equinoctial, close by γ Draconis. It is always worth remembering that the Colures are marked by Polaris, near which they intersect, by β Cassiopeæ and δ Ursæ Majoris, which show the direction of the Equinoctial Colure, and by γ Draconis, (in the Dragon's Head,) which shows the direction of the Solstitial Colure. In fig. 21 the colures and the circumpolar constellations are represented.



120 *Pole of the Ecliptic and the Sun's Motion.*—The position of the Pole of the Ecliptic is shown at E, fig. 21. It is nearly in the imaginary line joining Polaris and γ Draconis, half way between the Pole and the Dragon's Head, which is worth remembering. The Ecliptic is, as has been stated, the great circle along which the Sun appears to move from west to east at the rate of nearly one degree daily, so completing the entire circle in 365 days in round numbers. The sun is therefore always 90° from a point of the heavens about half way between Polaris and the Dragon's Head.

121 About the third week in March and September the Sun crosses the great circle, passing through Polaris and β Cassiopeæ, and at the corresponding period in June and December he crosses the great circle, passing through Polaris and γ Draconis. We shall find it convenient to divide each of the two Colures into semicircles, and consider that there are four Colures, which we shall call *Vernal, Summer, Autumnal,* and *Winter* Colures. The half great circle drawn from pole to pole through β Cassiopeæ nearly is the Vernal Colure, because the Sun crosses it in spring. The other half of the Equinoctial

Colure is the Autumnal Colure, because the Sun crosses it in autumn. The half great circle drawn from pole to pole through γ Draconis nearly is the Winter Colure, because the Sun crosses it in winter; and the other half of the Solstitial Colure is the Summer Colure, because the Sun crosses it in summer.

The four Colures, therefore, are marked as follows:—

The Vernal Colure—by Cassiopea.
The Summer Colure—by Camelopardus.
The Autumnal Colure—by the Septemtriones.
The Winter Colure—by the Dragon's Head.

The Sun's distance from the Pole is, when he crosses

The Vernal Colure, 90°.
The Summer Colure, about 66½°.
The Autumnal Colure, 90°.
The Winter Colure, about 113½°.

Having dwelt at some length on the circumpolar constellations for the reason above mentioned, we must now allude only briefly to the other constellations, at least the principal of them.

V. *Region of the Heavens along the Vernal Colure.*

122 In fig. 22 (see next page) this region is shown extending from Cassiopea to the Equator, and some way south of it. The first group of stars that catches the eye in this region is the square formed by the four stars, Alpherat, Algenib, Markab, and Scheat, shown in the figure. The Vernal Colure, which, it will be remembered, is drawn from the Pole through β Cassiopeæ nearly, passes through Alpherat and near Algenib, the two eastern stars of this square.

123 *Andromeda.*—The constellation Andromeda comes next after Cassiopea, as we go from the Pole to the Equator along the Vernal Colure, lying on the *east* side of the Colure: Alpherat is α Andromedæ.

124 *Pegasus.*—This constellation is on the western side of the Colure, Markab, Sheat, and Algenib, are α, β, and γ Pegasi.

125 *Pisces, the Fishes.*—This constellation is figured as two fishes tied together by a long string. One fish is marked by three small stars a little west of the Colure, just below Algenib and Markab. The other fish is higher up, near Andromeda, on the east of the Colure. This is one of the twelve constellations, called the Signs of the Zodiac.

126 *Aries, the Ram.*—The head of Aries is marked by two stars of the third magnitude, easily recognised, situated some way east of the Colure. Aries is one of the signs of the Zodiac.

127 *Vernal Equinoctial Point.*—The figure shows the equator and ecliptic meeting the Colure at the vernal equinoctial point, which is about as far below Algenib, as Algenib is below Alpherat. The Sun's proper motion takes place along the ecliptic in the direction represented by the arrow, contrary to the diurnal rotation of the heavens, the direction of which is represented by the arrow pointing along the equator.

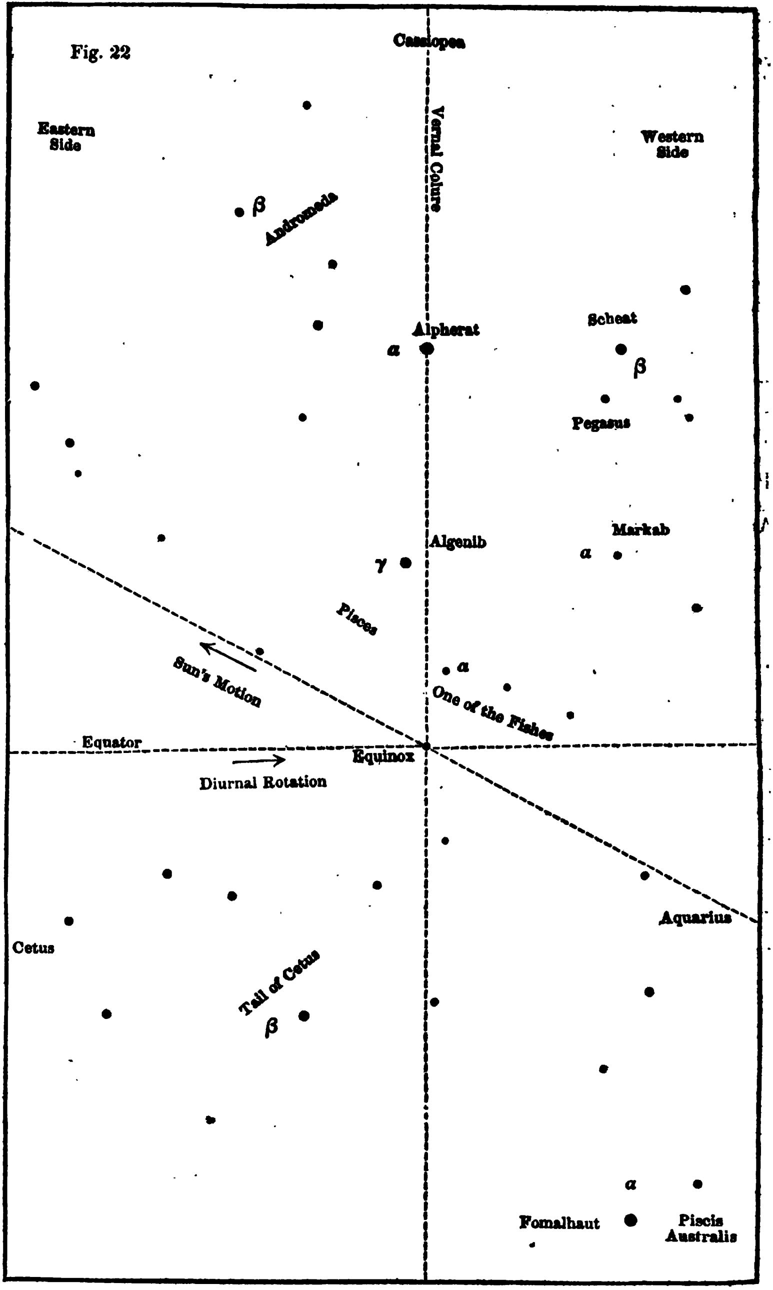
128 The equinoctial point is continually but very slowly moving along the ecliptic, in a direction contrary to that of the Sun's proper motion. This point was formerly in Aries, and was called the First Point of Aries. It is now in Pisces, and is moving towards Aquarius. It still, notwithstanding, retains the name of the First Point of Aries.

129 *Aquarius, the Waterman.*—This is another of the signs of the Zodiac, next to Pisces, but lower down, on the western side of the Colure.

130 *Cetus, the Whale.*—Opposite Aquarius, on the other side of the Colure, is a large constellation, called Cetus, the stars of which, near the tail, are shown in the figure.

131 *Piscis Australis, the Southern Fish.*—A bright star of the first mag-

Fig. 22


Cassiopea
Eastern Side
Western Side
Vernal Colure
β
Andromeda
Alpherat
α
Scheat
β
Pegasus
Markab
α
Algenib
γ
Pisces
α
One of the Fishes
Sun's Motion
Equator
Equinox
Diurnal Rotation
Aquarius
Cetus
Tail of Cetus
β
α
Fomalhaut
Piscis Australis

nitude, called Fomalhaut, which means the Fish's Mouth, being a corruption of an Arabic word, marks the mouth of the Southern Fish, which lies immediately below Aquarius. This star being so much to the south of the equator, is never seen much above the horizon in these latitudes, and is therefore seldom visible, the stars near the horizon being generally obscured by mists and clouds; besides, the more to the south a star is, the shorter time is it above the horizon each day.

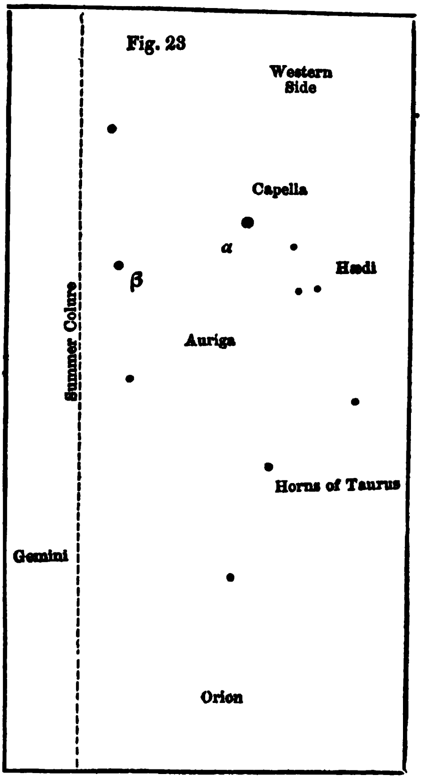


Fig. 23

VI. *Region of the Heavens along the Summer Colure.*

132 *Auriga, the Charioteer.*—The first remarkable group that catches the eye as we go from the Pole along the Summer Colure, is the beautiful constellation of Auriga, shown in fig. 23, which lies close to the Colure, on the western side. The brilliant star, *Capella*, or the Goat, is the Lucida of this constellation, near which lie three little stars, called *Hædi*, or the kids. The two stars below Auriga, in the figure, are the tips of the horns of *Taurus*, the Bull, one of the signs of the Zodiac. The upper of these two stars, together with *a* and *β* of Auriga, form an isosceles triangle, or with two other smaller stars, shown in the figure, make an irregular pentagon. This pentagon is a remarkable object in the heavens, on account of Capella and the Hædi, which, once pointed out, are always recognised again immediately.

133 *Taurus, the Bull. The Hyades and Pleiades.*—The horns of Taurus, as we have stated, lie below Auriga, a little west of the Colure. Taurus contains the two groups, the Pleiades and Hyades, so often alluded to in the ancient poets (see fig. 24, on next page); the Hyades form the face of Taurus, and the Pleiades the shoulder. The star, Aldebaran, is one of the Hyades; it is of the first magnitude, but not brilliant. The Pleiades are very small and close together, but they glisten with a remarkable degree of brightness; only six of them can be seen by most persons, but a good eye detects a seventh, and sometimes one or two more, and hence the story of the lost Pleiad. The Pleiades derive their name from πλεῖν, to sail, because they were supposed to indicate the season favourable to navigation; they were called Vergiliæ by the Latins. In Cicero's translation of Aratus we find:—

> Parvas Vergilias tenui cum luce videbis
> Hæc septem vulgo perhibentur more vetusto
> Stellæ cernuntur vero sex undique parvæ.

'You will behold the little Vergiliæ faintly shining. These are commonly said to be seven in number, after the ancient tradition, but only six small stars can be seen.'

Fig. 24

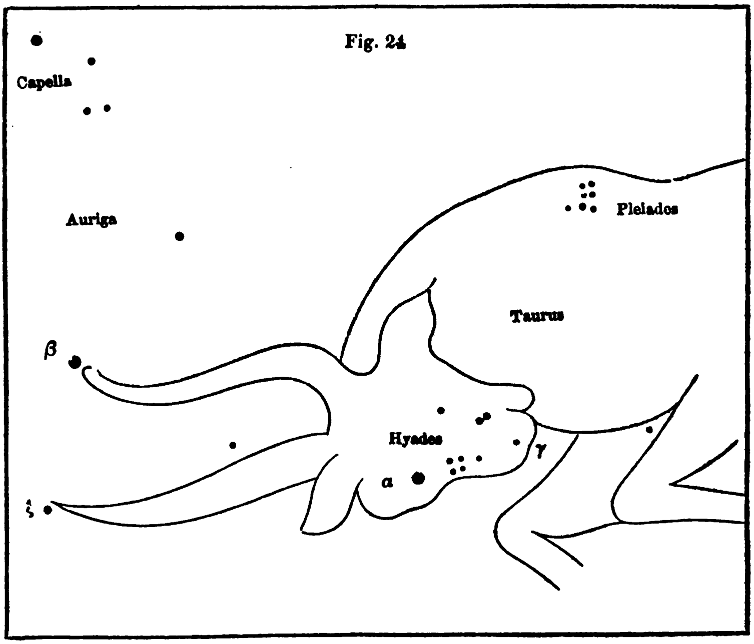
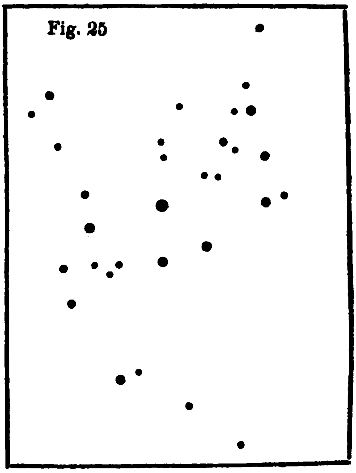


Fig. 25 shows a telescopic view of the Pleiades.

Fig. 25

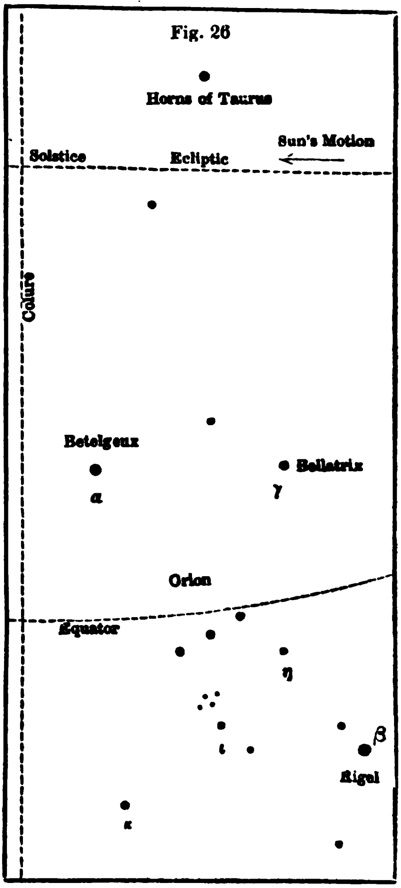


The Hyades were supposed to indicate rain, and hence their name, from ὕειν, to rain; they were, by a mistaken translation, called Suculæ, or little pigs, by the Latins, (*Cicero de Nat. Deorum*, lib. ii. cap. 43.)

134 *Orion.*—This splendid constellation lies below the horns of Taurus,

close on the western side of the Colure; it is represented in fig. 26; like the Hyades and Pleiades, it is continually alluded to by the Greek and Roman writers. The stars α and β, *Betelgeux* and *Rigel*, are of the first magnitude; γ, or *Bellatrix*, and the three stars which form Orion's Belt, are of the second magnitude. The stars η, ι, and κ form the sword; close to ι are a great number of small stars, and a most remarkable nebula, which had never been resolved into stars until Lord Rosse's telescope was brought to bear upon it.

Fig. 26

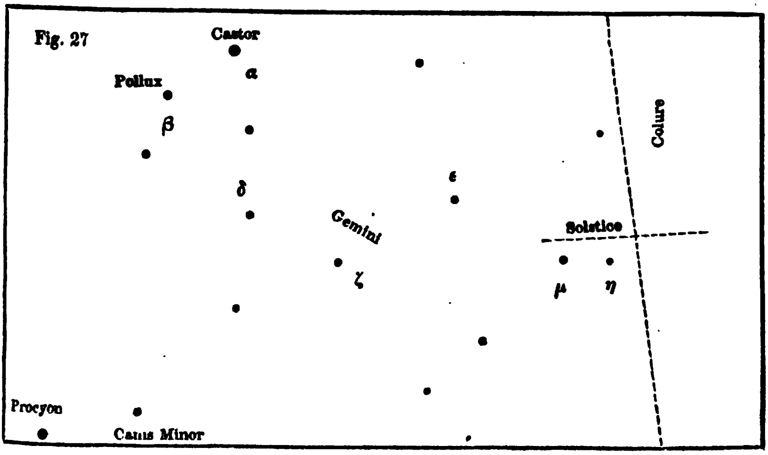


135 *Gemini, the Twins.*—We shall now briefly mention the constellations on the eastern side of the Summer Colure. The constellation Gemini, shown in fig. 27, is opposite the horns of Taurus, close to the Colure on the eastern side. The bright stars, α and β, *Castor* and *Pollux*, were anciently much noticed, especially by mariners. Gemini is one of the signs of the Zodiac.

136 *Canis Minor, the Little Dog.*—Under Gemini, but more to the east, is Canis Minor, which contains only two stars that are readily noticed by the eye. One of these, α, or *Procyon*, is a brilliant star of the first magnitude. See fig. 27.

137 *Canis Major, the Great Dog.*—Some way farther downwards, close to the Colure, and on the eastern side, is the celebrated constellation, Canis Major, containing the brightest star in the heavens,

Fig. 27



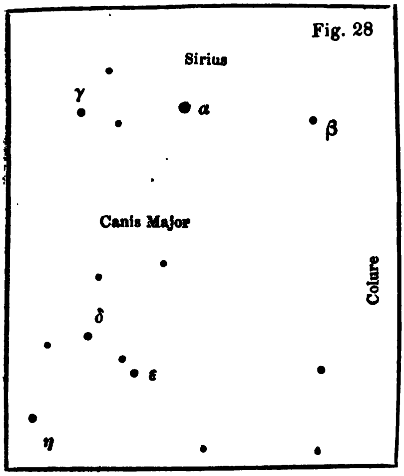


Fig. 28

Sirius, or the *Dog Star*. See fig. 28. The star Aldebaran of the Hyades, the Belt of Orion, and Sirius, are nearly in the same straight line. There is no possibility of missing Canis Major, if we look a little below Orion, and somewhat to the east of it.

138 In ancient times, the dog days, which commenced when Sirius rose at the dawn of day, were considered to be most fatal in producing fevers and madness; but these days are chiefly to be noticed on account of their chronological importance with reference to the *Annus Magnus*, or *Great Year*, of the Egyptians. We have the following passage from Censorinus, (*Cory's Ancient Fragments*):—

'Ad Ægyptiorum vero magnum annum luna non pertinet, quem Græci Κυνικὸν, Latine Canicularia vocamus. Propterea quod initium illius summitur, cum primo die ejus mensis, quem vocant Ægyptii Θὼθ, Caniculæ sidus exoritur,' &c. &c.

The substance of what he says is this:—That the *Great Year* of the Egyptians was not determined by the Moon, but by the fact of their civil year containing always 365 days, without any leap year, which caused a slow change of the seasons, in consequence of the year being nearly six hours shorter than it ought to have been. This change was completed in 1461 years, at the end of which period the seasons all came back to their proper places in the year. This period of 1461 years was called the Great Year; also, by the Greeks, the *Cynic*, or Dog Year; and by the Latins, the *Canicular* Year, because it began when the Dog Star rose at dawn, on the first day of the Egyptian month *Thoth*. But the year which Aristotle calls *the Greatest*, rather than *the Great*, is that in which the Sun, Moon, and planets all return and come together in the same sign of the Zodiac from which they originally started. The winter of this year is the *Cataclysm*, or Deluge, the summer is the *Ecpyrosis*, or Conflagration of the World.

Theon of Alexandria gives an example of a formula for finding the rising of the Dog Star, entitled, ΠΕΡΙ τῆς τοῦ κυνὸς ἐπιτολῆς ὑπόδειγμα.

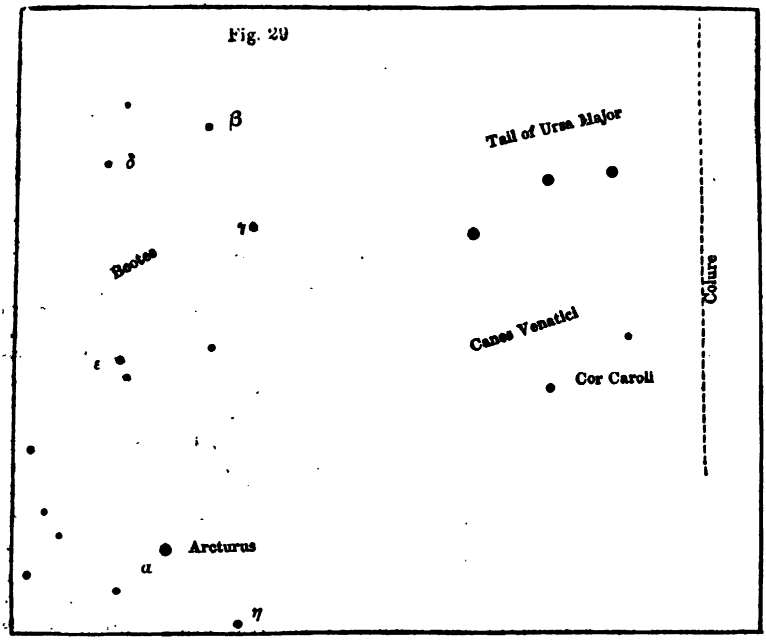
The connexion between astronomy and chronology that is thus established by the numerous references of ancient writers to astronomical phenomena, is most interesting and important, inasmuch as astronomy can as accurately tell the past, as predict the future motions of the heavenly bodies, and therefore it becomes an instrument for penetrating through the dimness of antiquity.

139 *Summer Solstice—Ecliptic—Equator.*—The ecliptic runs midway between the Hyades and Pleiades, also between the horns of Taurus. The solstitial point is close to the stars η and μ Geminorum. The equator runs through the top star of Orion's belt very nearly, a little beyond which, towards Procyon, is the point of the equator which is 90° from each equinox.

VII. *Region of the Heavens along the Autumnal Colure.*

140 *Canes Venatici, the Hounds.*—The Autumnal Colure is drawn from the Pole towards the tail of Ursa Major; it runs between γ and δ Ursæ Majoris, close by δ. On the eastern side of this Colure, and immediately below the tail, are the two Hounds of Bootes, fig. 29, in the neck of one of which is the star often called *Cor Caroli*, the Heart of Charles (II). These hounds do not belong to the ancient constellations.

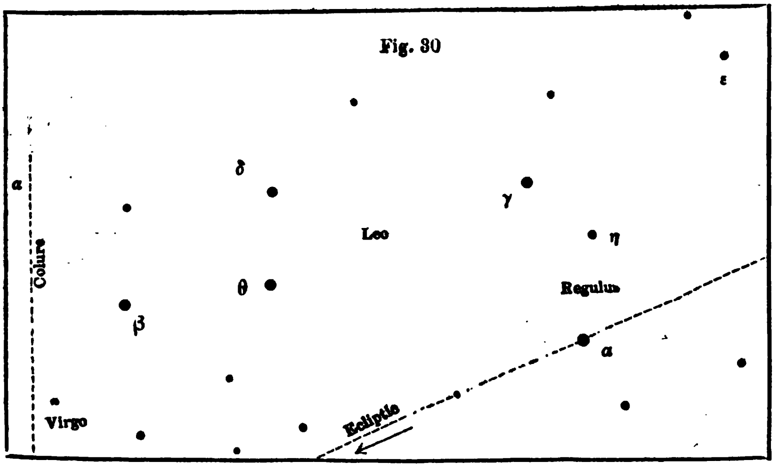
Fig. 29



141 *Bootes, the Herdsman*, is made up of the bright stars to the east and south east of Cor Caroli, among which *Arcturus* shines conspicuously. (See fig. 29.) Arcturus is found by drawing an imaginary line through β Ursæ Majoris, which runs a little above Cor Caroli, and, farther on, a little below Arcturus.

142 *Coma Berenices, the Hair of Berenice.*—A group of small, bright stars close on the eastern side of the Colure, and due west of Arcturus. See fig. 31.

Fig. 30



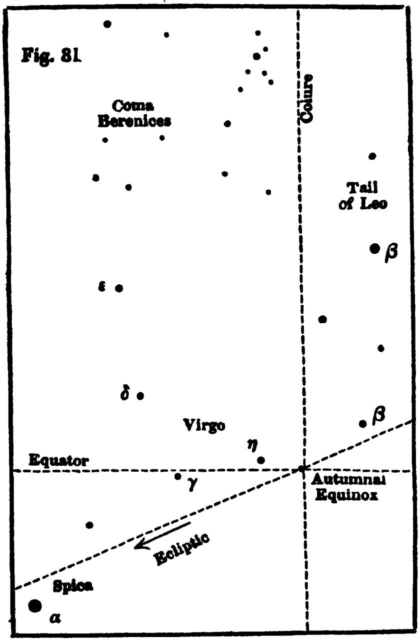


Fig. 31

143 *Leo, the Lion.*—One of the signs of the Zodiac on the west of the Colure, and opposite Arcturus. (See fig. 30.) α Leonis, (which is also called Cor Leonis, the Lion's Heart, and Regulus,) is a star of the first magnitude. β Leonis is called *Deneb,* or the Tail; it is within 5° of the Colure.

144 *Virgo, the Virgin.*—Another of the signs of the Zodiac, immediately under Coma Berenices, and all, except a few stars, lying on the east of the Colure—see fig. 31. The star α of this constellation is called *Spica,* or the ear of corn, and is of the first magnitude.

Arcturus, Regulus, and Spica being joined by imaginary lines, form a right-angled triangle, having the right angle at Spica: which fact being remembered, will prevent any mistake about the position of these stars.

145 *Autumnal Equinox—Ecliptic—Equator.*—The autumnal equinoctial point is close to η Virginis, fig. 31. The ecliptic runs through Regulus, and nearly through, but a little above, Spica. The equator is shown in the figure, passing through η Virginis nearly.

VIII. *Region of the Heavens along the Winter Colure.*

146 *Lyra, the Lyre; and Cygnus, the Swan.*—The winter Colure is drawn from the Pole nearly through γ in the Dragon's Head; farther on, we come upon Lyra, in which is the bright star Vega, of the first magnitude. Lyra is near the Colure on the eastern side; Cygnus is east and somewhat northeast of Lyra, not far from Cepheus. The five brightest stars of Cygnus form a cross, of which α, or *Deneb,* the tail, is of the first magnitude. Lyra and Cygnus are shown in fig. 32.

147 *Hercules, and Corona Borealis, the Northern Crown.* — Hercules includes the stars opposite and a little south of Lyra on the other—i. e., the western side—of the Colure. West of these is Corona Borealis, which is nearly a circlet of stars, one, α, being of the second magnitude, (see fig. 33,) α Herculis is a variable star.

148 *Aquila, the Eagle; and Delphinus, the Dolphin.*—Somewhat south of Cygnus and Lyra, on the eastern side of the Colure, we find Aquila and

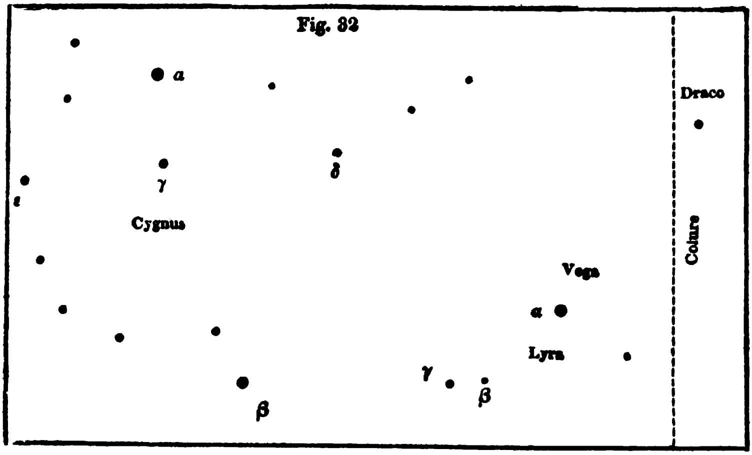


Fig. 32

α
δ
γ
ε
Cygnus
Draco
Colure
Vega
α
Lyra
γ
β
β

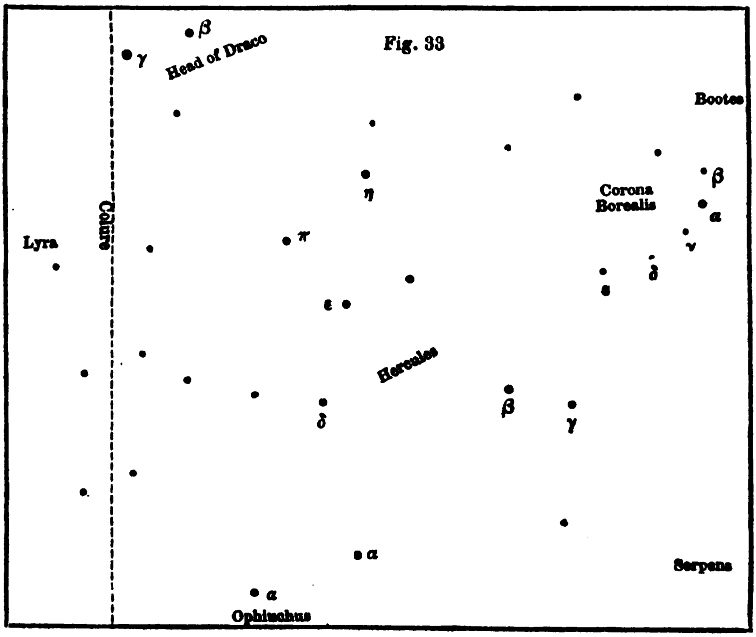


Fig. 33

β
γ
Head of Draco
Bootes
η
β
Corona Borealis
α
γ
Lyra
Colure
π
δ
ε
ε
Hercules
β
δ
γ
α
α
Ophiuchus
Serpens

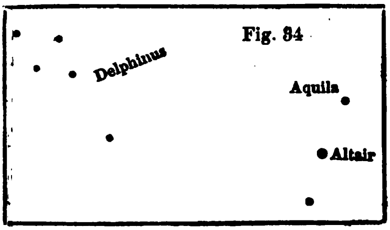


Fig. 34

Delphinus, fig. 34. The stars of Delphinus are very bright, though small, and form a diamond-shaped figure. α Aquilæ, is a star of the first magnitude; it is called *Altair.* The three stars, β α and γ Aquilæ, (which are in a line,) with the diamond-shaped and glistening Delphinus, are remarkable objects in the heavens, and not likely to be forgotten when once seen.

149 *Ophiuchus, the Snake Holder; and Serpens, the Snake.*—These two constellations lie on the east of the Colure below Hercules, and include a number of bright stars. See fig. 35.

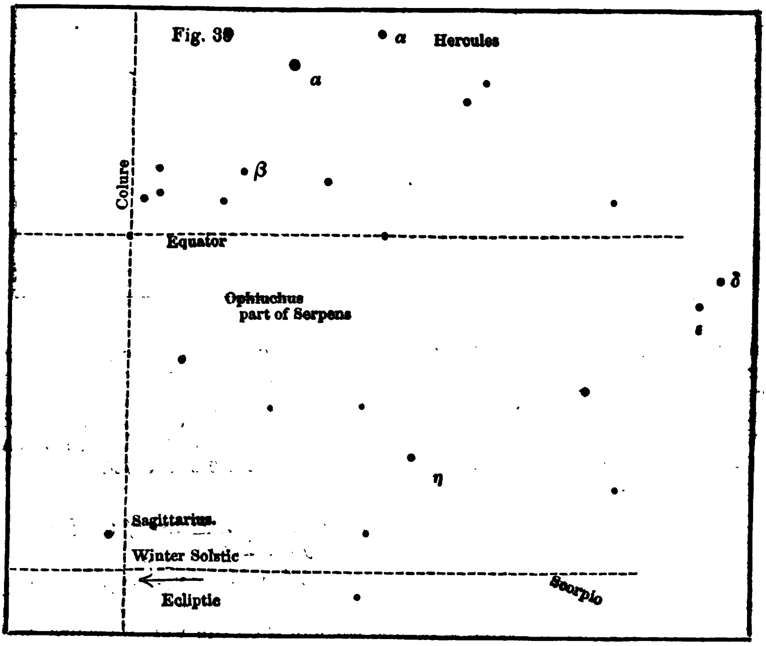


Fig. 35

150 *Libra, the Balance; Scorpio, Sagittarius, and Capricornus.*—These are four of the signs of the Zodiac. Scorpio and Sagittarius are shown in fig. 36. α Scorpionis is a star of the first magnitude, called *Antares.*

Sagittarius is close on the east of the Colure, and Scorpio somewhat farther off on the west. Scorpio is a remarkable constellation, and easily recognised.

151 *Winter Solstice—Ecliptic—Equator.*—The ecliptic runs between β and δ Scorpionis, and a few degrees below μ Sagittarii, immediately under which star is the winter solstitial point. The equator lies about 8° below Altair.

152 We have now sufficiently pointed out the position and appearances of a sufficient number of the principal constellations, in such an order that it will be easy to find them out and remember them. We have dwelt at some length on this part of the subject, because mere maps or figures of the con-

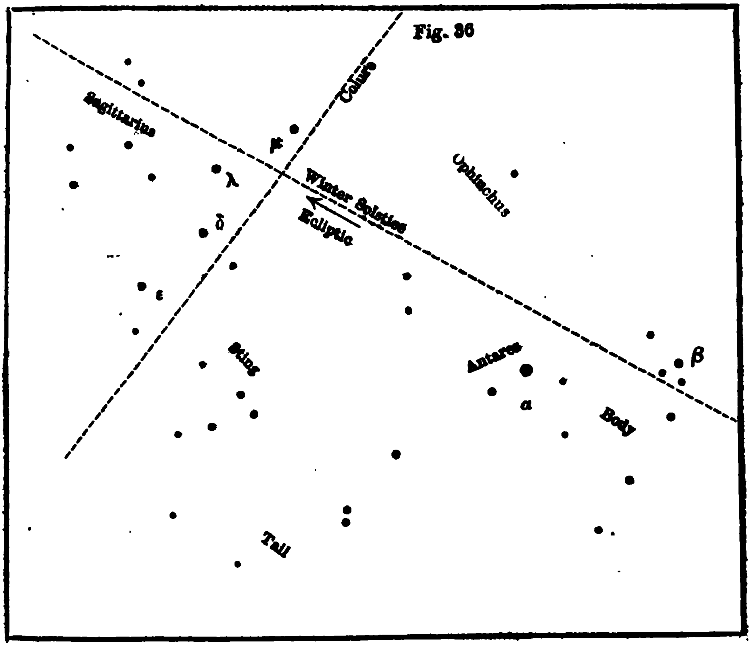


Fig. 36

stellations, without any remarks respecting them, do not produce much effect on the memory. For complete and accurate information, we may refer the reader to the six maps of the stars published by the Society for the Diffusion of Useful Knowledge, and to Smyth's *Celestial Cycle,* vol. ii. We shall conclude this chapter with a few words on the stars and constellations which come on the meridian at certain hours at different times of the year.

IX. *Constellations visible on the Meridian at different Hours of the Night, and at different Seasons of the Year.*

153 It is easy to make out what stars are on the meridian at midnight at any particular time of the year, by considering the position of the Sun in the heavens: thus, at the Vernal Equinox, the sun is on the Vernal Colure, and therefore at midnight, when the Sun is on the meridian *below* the horizon, the Vernal Colure must be so also, and therefore the Autumnal Colure must be on the meridian *above* the horizon. Hence all the stars lying along the Autumnal Colure will be on the meridian at midnight at the Vernal Equinox.

It is also easy to make out what stars are on the meridian at any other hour, by making the proper allowance for the diurnal rotation of the heavens.

154 The following table exhibits the constellations visible on or near the meridian at nine o'clock, (three hours before midnight,) at different times of the year.

Third week in March.	Head of Ursa Major. Cancer. Head of Leo. Regulus. Cor Hydræ.	A
„ April.	The Pointers. Deneb. Tail of Leo. Coma Berenices. Head of Virgo.	B
„ May.	Tail of Ursa Major. Cor Caroli. Bootes. Arcturus. Coma Berenices. Virgo. Spica.	C
„ June.	Body of Ursa Minor. Bootes. Corona Borealis. Head of Serpens. Libra.	D
„ July.	Tail of Ursa Minor. Head of Draco. Hercules. Ophiuchus and Serpens. Scorpio.	E
„ August.	δ Draconis. Cygnus. Lyra. Vega. Aquila. Altair. Sagittarius.	F
„ September.	Cepheus. Tail of Cygnus. Delphinus. Head of Pegasus. Aquarius. Capricornus.	G
„ October.	β Cassiopeæ and Head of Cepheus. Scheat. Markab. Pegasus. Pisces, (western fish.) Tail of Cetus. Aquarius. Fomalhaut.	H
„ November.	δ and γ Cassiopeæ. Andromeda. Aries. Pisces, (eastern fish.) Alpherat. Algenib. Tail of Cetus.	I
„ December.	Perseus. Algol. Pleiades. Aries. Head of Cetus. Eridanus.	J
„ January.	Capella. Auriga. Hyades. Gemini. Canis Minor. Orion. Canis Major.	K
„ February.	Gemini. Castor and Pollux. Canis Minor. Procyon. Canis Major. Sirius.	L

155 We have chosen nine o'clock in the above table as a convenient for observing the stars, instead of midnight, which would be rather la most people. The table may, however, be easily adapted to any hou means of the following, in which A B C &c. denote the constellatio the above table.

Table showing the Constellations on or near the Meridian at differen Hours in different Months.

	EVENING.				MORNING.			
	5 o'clock.	7 o'clock.	9 o'clock.	11 o'clock.	1 o'clock.	3 o'clock.	5 o'clock.	o'c
March . .	K	L	A	B	C	D	E	[illegible]
April . .	L	A	B	C	D	E	F	[illegible]
May. . .	A	B	C	D	E	F	G	[illegible]
June . .	B	C	D	E	F	G	H	[illegible]
July. . .	C	D	E	F	G	H	I	J
August. .	D	E	F	G	H	I	J	K

TABLE—*continued.*

	EVENING.				MORNING.			
	5 o'clock.	7 o'clock.	9 o'clock.	11 o'clock.	1 o'clock.	3 o'clock.	5 o'clock.	7 o'clock.
September.	E	F	G	H	I	J	K	L
October .	F	G	H	I	J	K	L	A
November.	G	H	I	J	K	L	A	B
December.	H	I	J	K	L	A	B	C
January . .	I	J	K	L	A	B	C	D
February .	J	K	L	A	B	C	D	E

For example: What constellations will be on or near the meridian at seven o'clock in February? Looking in the column under seven o'clock, we find K opposite February; and therefore, referring to the former table, to see what constellations are represented by K, we find that Capella, Auriga, the Hyades, Gemini, Canis Minor, Orion, Canis Major, will be on or near the meridian at the time specified.

X. *Signs of the Zodiac.*

156 As the motions of the Sun, Moon, and Planets take place among these constellations, it is necessary to say something respecting them. The Zodiac is the celestial region lying along the Ecliptic; its name is derived from ζῴδιον, *zodion*, a little animal, because its different parts are marked by figures of animals. Fig. 37 shows the animals as represented on the ceiling of

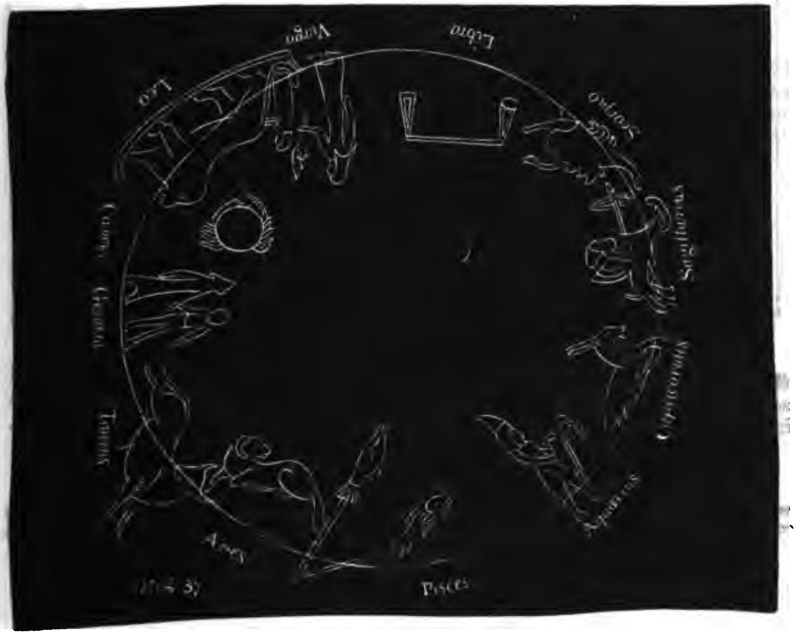


Fig. 37

an apartment in the Temple of Denderah in Egypt, which we may conclude, from inspecting the ceiling, was adorned with these curious figures about 700 B.C. See *Penny Cyclopædia*, Art. *Zodiac*, where an account of the ceiling is given, together with information respecting the ancient constellations.

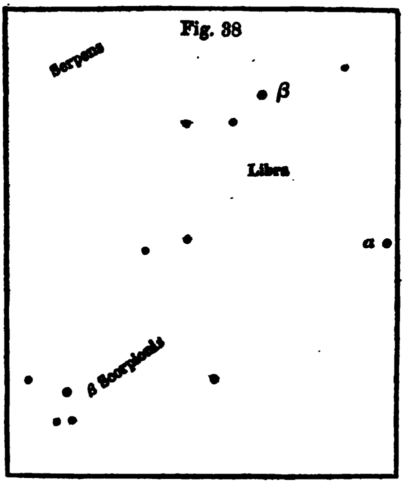


Fig. 38

157 The order of the Zodiacal signs, and the symbols by which they are represented, are as follows:—

Aries, the Ram	♈
Taurus, the Bull . . .	♉
Gemini, the Twins . . .	♊
Cancer, the Crab . . .	♋
Leo, the Lion	♌
Virgo, the Virgin . . .	♍
Libra, the Balance . . .	♎
Scorpio, the Scorpion . .	♏
Sagittarius, the Archer .	♐
Capricornus, the Goat .	♑
Aquarius, the Waterman .	♒
Pisces, the Fishes . . .	♓

We have already spoken of the stars composing all these constellations, except Cancer, Libra, and Capricornus, which are shown in figs. 38, 39, and 40.

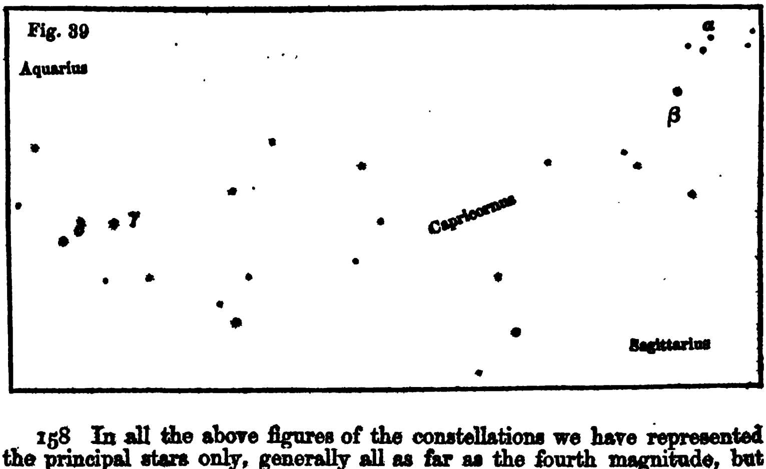


Fig. 39

158 In all the above figures of the constellations we have represented the principal stars only, generally all as far as the fourth magnitude, but sometimes as far as the fifth, where such stars were necessary to be put down, in order to make it easy to find out the constellation in the heavens.*

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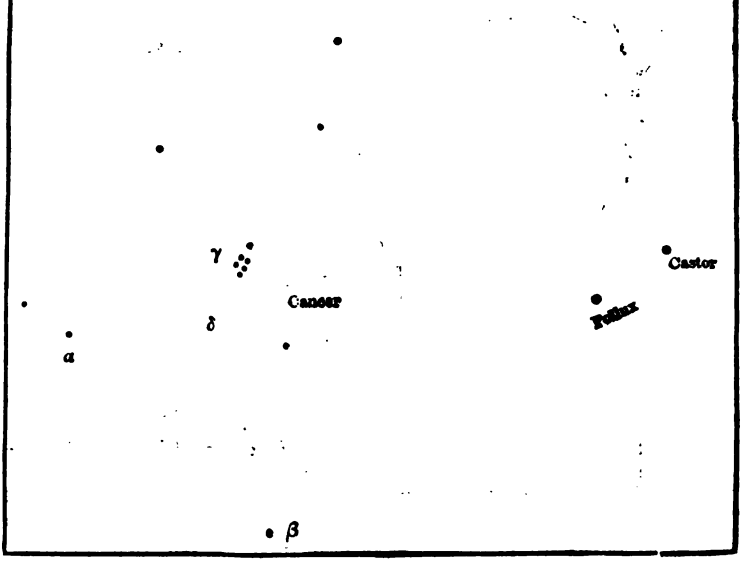
* The different magnitudes of the stars are not represented as accurately as in the drawings sent to the engraver, but there are no errors of any consequence. In a few of the figures the constellations are a little distorted in shape.

Fig. 40



CHAPTER III

ASTRONOMICAL TERMS EXPLAINED.—MEASUREMENT OF TIME.

BEFORE we proceed to the practical application of Astronomy, it will be necessary to explain the meaning of certain terms constantly made use of in the science, whereby the positions and the motions of heavenly bodies are defined, and to describe the different measures and periods of time, which is so important an element in astronomical observations and calculations.

I. *Terms relating to Vertical and Horizon*

160 *Vertical.*—When a body is allowed to fall towards the Earth's surface, it describes a straight line tending towards the centre of the Earth nearly. We say nearly, because, on account of the Earth not being exactly spherical, bodies do not fall exactly towards the centre. The motion of falling bodies is produced by the attraction of the Earth, or the attraction of *Gravity*, as it is called. If the body, instead of being allowed to fall, is suspended by a string ,the string shows the direction in which the body would fall, if allowed to do so, because it shows the direction in which the force of gravity pulls the body.

The straight line which a falling body describes is called the *Vertical* or *Vertical Direction*. This direction is determined by suspending a heavy body, such as a piece of lead, by a string, and then the string will show the vertical. A string thus used is called a plumb line (from *plumbum*, lead).

161 The vertical is, then, the direction in which the force of gravity acts, and therefore Astronomers always determine or observe the vertical

direction by means of the force of gravity. We must remark, however, that in the neighbourhood of large mountain masses, especially where there is a flat country on one side, and mountains on the other, the direction of the force of gravity is sensibly, though very slightly, affected by the attraction of the mountains. In this case the plumb line is said to be drawn out of the proper vertical, which is considered to be the direction in which the force of gravity would act, if the ground were on all sides perfectly level. We must, therefore, in defining the vertical to be the direction in which a plumb line hangs, add, that the Earth's surface is supposed to be perfectly level, or, in other words, to be the same as the surface of the ocean would be if it covered the whole Earth.

162 We must also observe, that when a body is allowed to fall from a very considerable height, it falls a little eastward of the true vertical (as shown by a plumb line), in consequence of the Earth's rotation about its axis. The deviation from the vertical is, however, extremely small.

163 *Horizontal.* The plane to which the vertical line is perpendicular is called the *Horizontal Plane.* The surface of still water, or any other fluid, such as mercury, shows the horizontal plane, provided it be of limited extent: for fluid surfaces of considerable extent are sensibly curved, as we see in the case of the ocean. Astronomers employ this property of fluids to determine the horizontal plane, as we shall presently explain when we come to speak of the Spirit Level, and the method of observing heavenly bodies reflected in a trough of mercury.

164 Every plane containing the vertical line, or, what is the same thing, every plane perpendicular to the horizontal plane, is called a *Vertical Plane.* The intersection of two vertical planes is therefore a vertical line.

165 *Zenith and Horizon.*—We have, in the previous chapter, explained what the celestial sphere is, and what great circles and small circles are. The points of the celestial sphere, where the vertical line produced meets it, are called the *Zenith* and *Nadir* (terms of Arabic origin), the zenith being the point of the celestial sphere exactly over the observer's head, and nadir the opposite point beneath his feet.

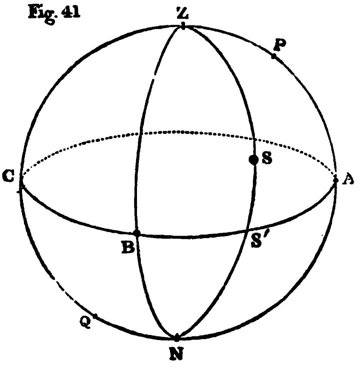
166 The horizontal plane cuts the celestial sphere in a great circle, which is called the *Horizon.* The word was originally applied to the circle which sensibly bounds the view of a spectator at sea, or on a height, and hence the word is derived from the Greek ὁρίζω, to bound or limit.

The Horizon is therefore a great circle of the celestial sphere, the poles of which are the zenith and nadir. Every point of the Horizon is 90° from the zenith.

167 *Meridian.*—That vertical plane in which the Earth's axis of rotation lies is called the *Meridian Plane,* or *Plane of the Meridian:* and the great circle in which this plane cuts the celestial sphere is called the *Meridian.* The Meridian is therefore the great circle which passes through the North and South Poles and the Zenith. The name is derived from the Latin word signifying half-day, or mid-day, because it is mid-day when the Sun crosses the Meridian.

168 *Altitude and Azimuth.*—Let A B C, fig. 41, represent half the Horizon, P and Q the North and South Poles, Z and N the Zenith and Nadir, and A P Z C Q N the Meridian: let S denote the position of any star on the celestial sphere, and let a great circle be drawn through Z and S meeting the horizon at S′. Then the circular arc S S′ expressed in degrees, minutes, and seconds, is called the *Altitude* of the star S, and the circular arc A S′, expressed similarly, is called the *Azimuth* of the star.

Fig. 41



The arc Z S, in degrees, minutes, and seconds, is called the *Zenith Distance* of the star; Z S is the *complement* of S S′—i. e., Z S added to S S′ *completes* or makes up 90°.

Since the circular arc S S′ shows how high the star is on the celestial sphere above the horizon, it is properly called the Altitude of the Star. The word Azimuth is a corruption of an Arabic word signifying 'the way' or 'distance,' meaning thereby the number of degrees, minutes, and seconds we must go along the horizon A B C, from the point A, in order to get to S′, which point marks the vertical plane in which the star is.

169 The position of a star on the celestial sphere is completely defined by stating its altitude and azimuth; for example, if the altitude of the star be 30° and its azimuth 50°, we find the place of the star by measuring along the horizon from A, a circular arc A S′ equal to 50°, then from S′ drawing a great circle to Z, and measuring S′ S equal to 30°, which will give the place of the star S.

170 It is important to remember that the great circle Z S S′ N shows on the celestial sphere the vertical plane in which the star is; for this circle, since it passes through the zenith and nadir, Z and N, lies in a vertical plane, and therefore shows on the celestial sphere the vertical plane in which the star is. We shall speak of this plane as the plane Z S S′ N.

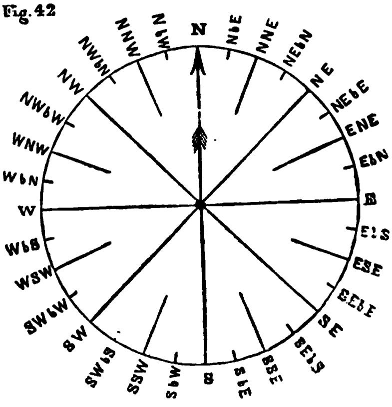
171 The arc A S′ shows the angle which this vertical plane makes with the meridian plane Z A N; for, if we conceive the semicircle Z S′ S N to turn about the points Z and N, the point S′ starting from A and moving towards B, it is clear that the number of degrees, minutes, and seconds through which the point S′ moves along the horizon, show the number of degrees, minutes, and seconds through which the vertical circle or plane Z S S′ N turns about the points Z and N, or, what is the same thing, the angle of inclination of the plane Z S S′ N to the plane of the meridian.

The angle at Z, which the two circles Z P A and Z S S′ make with each other, also shows the inclination of the plane Z S S′ N to the plane of the meridian; for, conceiving the plane Z S S′ N to turn as before, it is clear that the number of degrees, minutes, and seconds, in the angle at Z, which the arc Z S S′ makes with Z P A, shows the number of degrees, minutes, and seconds through the plane Z S S′ N turns about Z—i. e., its inclination to the plane of the meridian.

Hence the azimuth of a star shows the inclination of the vertical plane in which the star is to the meridian plane, or, what is the same thing, the angle which the zenith circle of the star makes with the meridian.

By the zenith circle of a star, we mean the great circle passing through the zenith and the star.

Fig. 42



172. *Prime Vertical.*—The vertical plane, which is perpendicular to the plane of the meridian, is called the *Prime Vertical Plane*, and the great circle in which this plane cuts the celestial sphere is called the Prime Vertical; in other words, the Prime Vertical is the zenith circle, Z B N, which cuts the horizon half way between A and C, B being supposed to be 90° from A.

173 *Points of the Compass.*—A, fig. 41, is called the North Point of the horizon, C the South Point, B the East Point, and the point opposite B (on the other half of the horizon) the West Point. These are generally known as the *Points of the Compass*, which are represented in fig. 42, the circle being the horizon, and N E S and W being the north,

east, south, and west points respectively. There are altogether thirty-two points of the compass, at equal distances from each other, dividing each quadrant of the horizon into eight equal parts, each part being therefore one-eighth of 90°—i. e., 11° 15′. Each of these divisions is supposed to be further subdivided into what are called *Quarter Points*, each containing 2° 48′ 45″, which make the fourth part of 11° 15′. It may be well to remember the following table for one quadrant, which will apply to the other quadrants by a simple change of points and corresponding letters.—

Azimuth.	Corresponding Point of Compass.		
0°	N.	North Point.	
	N. by E.	North by East.	One point (i. e., 11° 15′) East of North.
22° 30′	N.N.E.	North North East.	Half way between North and North East.
	N.E. by N.	North East by North.	One point North of North East.
45°	N.E.	North East.	Half way between North and East.
	N.E. by E.	North East by East.	One point East of North East.
67° 30′	E.N.E.	East North East.	Half way between East and North East.
	E. by N.	East by North.	One point North of East.
90°	E.	East Point.	90° from North.

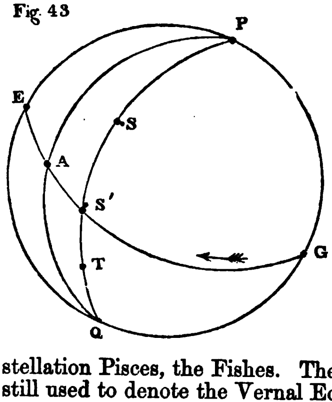
174 It should be borne in mind, that when a star is rising or setting, it is 90° from the zenith; and that the circumpolar motion of the heavens causes all the heavenly bodies which are at a sufficient distance from the Pole to cross the horizon twice in twenty-four hours, ascending or rising on the eastern side, and descending or setting on the western side.

II. *Terms relating to Pole and Equator.*

175 In the same manner that we define the place of a star with reference to the zenith and horizon, we may do also with reference to the Pole and Equator, by means of what are called *Right Ascension and Declination*, as we shall now explain.

176 Let P and Q (fig. 43) represent the north and south Poles, E A S′ G half the Equator, P E Q G the meridian, S any star, A the Vernal Equinoctial point of the Equator, P A Q a great circle passing through P A and Q, P S S′ Q a great circle passing through P S and Q, and cutting the Equator at S′. Every point of the Equator is 90° from each Pole. A is the point where the Sun crosses the Equator in spring, at which time he is moving northward. A is usually called *the first point of Aries*, because in former times, when these names were brought into use, the Vernal Equinoctial point was at the beginning of the constellation Aries, the Ram.

Fig. 43



At present the Vernal Equinoctial point, in consequence of its slow motion, called the *Precession of the Equinoxes*, is in the constellation Pisces, the Fishes. The name—‘First point of Aries’—is, however, still used to denote the Vernal Equinoctial point.

177 It is from this point that all distances along the Equator are measured, just as we have measured distances along the horizon from the north point. It should be remembered that this point moves round the Pole in twenty-four hours with the rest of the heavens, crossing the meridian when it comes to E, and again when it comes round on the other side to G, the motion being in the direction represented by the arrow in the figure. The imaginary

circles P A Q and P S S′ Q are of course supposed to be carried round by the circumpolar motion, always keeping at the same distance from each other.

178 The great circles P A Q and P S S′ Q, may be called *Polar Circles*, since they pass through the Poles; and the planes in which these circles lie may be called Polar Planes. The polar circle P A Q is the Vernal Colure, which, as we have already stated, is the great circle passing through the Poles and the Vernal Equinoctial point, or First Point of Aries, as it is called.

179 *Right Ascension and Declination.*—The circular arc A S′ is called the *Right Ascension* of the star S, and the circular arc S′ S is called its *Declination.* The arc P S is the complement of the declination, and is called sometimes the co-declination, but more frequently the *North Polar Distance* of the star.

Right Ascension and Declination completely determine the positions of heavenly bodies on the celestial sphere; thus, for example, if the right ascension of a star be 20° and the declination 40°, we find its position by measuring from A an arc A S′ of 20° along the Equator, then drawing a great circle from S′ to P and measuring upon it an arc S′ S of 40°, which will give S, the place of the star.

180 It is important to remark that right ascension is always measured from A, not in the direction of the arrow (fig. 43), but in the contrary direction. The reason of this is, that the Earth and planets move round the Sun and round their axes in the same way that we measure right ascension—i. e., contrary to the way in which the arrow points, which, as we have stated, indicates the direction of the apparent motion of the heavens caused by the real motion of the Earth round its axis in the opposite direction.

181 Declination is always expressed in degrees, minutes, and seconds; it is, so to speak, the altitude of the star above the Equator, or, we may say, the number of degrees, minutes, and seconds by which the star *declines* from the Equator,.using the word ‘decline’ in its original signification of ‘turning aside.’

182 If the star is below the Equator, as at T (fig. 43), S T is the declination of the star, and it is called *south declination*, because measured towards the South Pole, the declination of S being called north declination, because it is measured towards the North Pole.

183 The right ascension of a star is the distance, from the first point of Aries, of the point where the polar circle, in which the star is, cuts the Equator. The right ascension of a star shows also the angle which the polar plane, in which the star is, makes with the plane of the Vernal Colure. The angle at P, which the two circular arcs A P and S P make with each other, contains the same number of degrees, minutes, and seconds that the arc A S′ does (which may be easily seen as in the case Azimuth, previously explained): hence the angle, which the polar circle passing through the star makes, at the pole, with the Vernal Colure, shows the right ascension of the star. The polar circle passing through a star is often called its declination circle.

184 The right ascension of a heavenly body is often, or rather, generally, expressed in time, at the rate of one hour for 15°—(i. e., twenty-four hours for 360°), since the heavens turn round the Pole at this rate, every star describing 15° of its circular course in an hour. The reason of expressing right ascension in time will appear as we go on, especially when we come to speak of the transit instrument.

Thus, if we say that the right ascension of S is four hours, we mean that A S′ corresponds to four hours—i. e., that A S′ contains four times 15°, or 60°. A right ascension of six hours is 90°, of twelve hours 180°, of eighteen hours 270°, and of twenty-four hours 360°, which brings us round the whole equator.

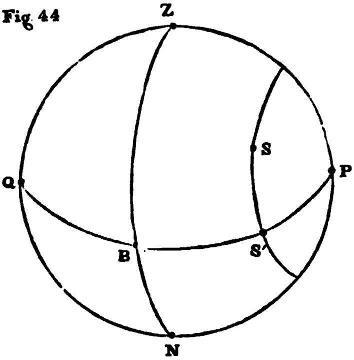
185 If the right ascension of S be four hours, A will evidently come on the meridian at E four hours before S′, for the space A S′ will be described in four hours, in consequence of the circumpolar rotation. Hence, observing that S and S′ come on the meridian at the same instant, we may define right ascension as follows:—

The right ascension of a star (expressed in hours, minutes, and seconds,) is the time that elapses between the transits across the meridian of the first point of Aries and the star. If the star crosses the meridian two hours, ten minutes, and eight seconds after the first point of Aries, its right ascension is two hours, ten minutes, and eight seconds, or briefly, $2^h\ 10^m\ 8^s$.

The Transit Instrument, of which we shall speak fully in a future chapter, is nothing more than an instrument for observing the times at which heavenly bodies cross the meridian, or, as it is said, the *transits* of heavenly bodies. It is perhaps the most accurate and important instrument used by astronomers.

186 *Origin of the terms Right and Oblique Ascension.*—These terms often occur in astronomical books, but the latter has now fallen into disuse. They have reference to the times of rising of heavenly bodies, as shown by the celestial sphere in what are called its *right* and its *oblique* positions. When the poles are in the horizon, as is the case when the observer is on the Earth's equator, the sphere is said to be a *right sphere*, for then all the heavenly bodies rise at right angles to the horizon. Fig. 44 represents a right sphere, P and Q being the poles, P B Q the horizon, S′ S the circular course of any star, which is evidently at right angles to the horizon at the point S′, where the star rises. In this case, the time elapsing between the rising of the first point of Aries an at of the star, was called the right ascension,—i. e., the time of the as on of the star above the horizon in the right position of the sphere.

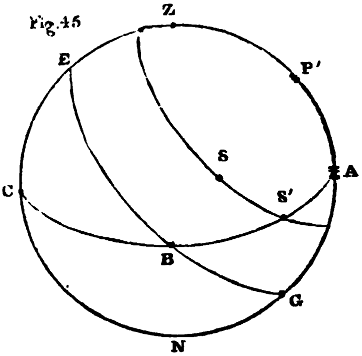
Fig. 44



When the poles, P and Q, are not in the horizon, A B C, fig. 45, the stars cross the horizon obliquely when they rise. In such a case the sphere is said to be *oblique*, and the time of ascension was called oblique ascension.

187 *Hour Angle.*—The angle which the polar circle, P S S′, fig. 43, makes at the pole, with the meridian, P E, is called the hour angle of the star S′, because, if reduced to time, at the rate of 1 hour for 15°, it shows what time must elapse before the star crosses the meridian. The number of degrees, minutes, and seconds, in this angle, is evidently the same as in the arc S′ E.

Fig. 45



188 *Latitude and Longitude of a Place.*—The terms latitude and longitude, with reference to a place on the Earth's surface, correspond to declination and right ascension, with reference to the celestial sphere. The Earth's surface, supposed to be spherical, is called the terrestrial sphere; the terrestrial equator is the great circle of the terrestrial sphere, every point of which is 90° from each of the terrestrial poles. The latitude of a point on the terrestrial sphere is the same thing as its declination; the longitude the same thing as its right ascension, with this difference, that the longitude is not measured from the first point of Aries, but from some fixed point of the terrestrial equator.

189 But this way of defining latitude and longitude is not sufficiently exact, taking into account the fact that the Earth's surface is not spherical. We must define these terms with reference to the celestial sphere in the following manner:—

Every place on the Earth's surface may be considered as marked upon the celestial sphere, by that point of the celestial sphere which is vertically over the place,—i. e., by the zenith of the place. The zenith of London marks the position of London, that of Paris the position of Paris, and so on; in fact, a correct map of the Earth's surface would be formed on the celestial sphere by marking the zenith of every place, and so tracing out on the celestial sphere the various coasts and boundaries of countries, the various towns, &c. &c., by their zeniths.

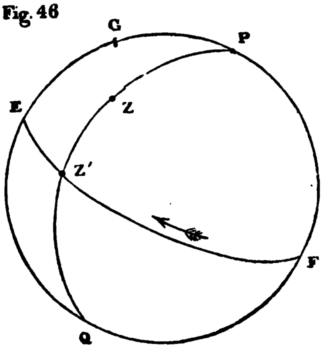
190 Taking, then, the zenith of a place as the point representing that place on the celestial sphere, we define latitude and longitude as follows:—

The latitude of a place is the declination of its zenith; the longitude of a place is the right ascension of its zenith, measured, however, not from the first point of Aries, but from some particular meridian, such as the meridian of Greenwich. Longitude is not measured from the first point of Aries, because that point is always moving over the Earth's surface, and longitude measured from it would be an ever varying quantity.

191 In fig. 46, P and Q represent the poles; E Z′ F, the equator; G, the zenith of Greenwich; P G E F, the meridian of Greenwich; Z, the zenith of any other place; P Z Z′ Q, the meridian of the place; then the arc Z Z′ is the latitude of that place, and E Z′ is its longitude.

192 The apparent motion of the heavens takes place in the direction of the arrow, and it must be remembered that the meridians P Z Q, and P E Q F, must be supposed to be fixed, while all the heavenly bodies appear to be carried round by the circumpolar motion. Since this motion takes place at the rate of 15° per hour, it is evident that, if the longitude of the place be 15°,—i. e., if E Z′ be 15°, every star will cross the meridian of the place, E Z Z′ Q, one hour before it crosses the meridian of Greenwich, P G E Q; if the longitude be 30°, every star will cross the former meridian two hours before the latter; if 45°, three hours, and so on.

Fig. 46

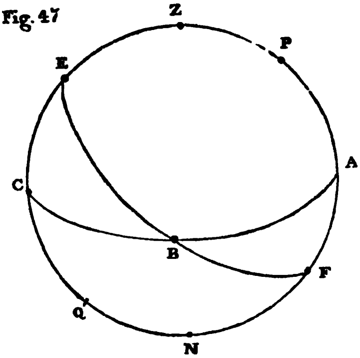


193 Longitude, thus considered, is measured towards the east, and is called east longitude. If measured towards the west, it is called west longitude.

194 *The Altitude of the Pole at any place shows the Latitude of that place.*—For let P, fig. 47, be the pole; Z, the zenith; A B C, the horizon; E B F, the equator: then E Z is the latitude of the place; E P is 90°, also Z A is 90°; therefore E Z=90°—Z P, and P A=90°—Z P.; therefore P A=E Z.

Now, P A is the altitude of P above the horizon A B C; hence the altitude of the pole is equal to the latitude of the place.

Fig. 47



195 The circular arc Z P is called the *co-latitude*, or the complement of the latitude, because with the latitude it makes up or completes 90°.

III. *Of Time, Sidereal and Solar.*

196 *Sidereal Time.*—The most accurate observations show that the apparent circumpolar motion of the heavens is perfectly uniform, always taking place at the rate of 15° in an hour, 15′ in a minute, 15″ in a second. Indeed, we may conclude from mechanical considerations, that the Earth's motion about its axis, and therefore the circumpolar motion of the heavens, is uniform. From this uniformity of motion, every star may be used as a clock to indicate and measure time, provided we have proper instruments for observing the motion of the star.

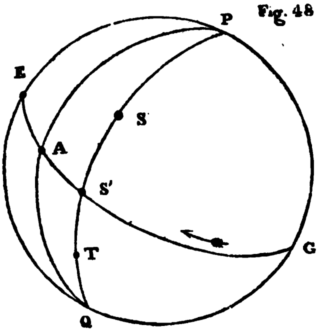
197 Time, measured by the motion of the stars, is called *sidereal time;* the interval of time in which a star completes its revolution is called a *sidereal day;* the twenty-fourth part of that interval, a *sidereal hour.* We must, of course, choose some particular star or point of the heavens to mark the sidereal hours by its motion; the first point of Aries is that fixed upon for this purpose. When the first point of Aries is on the meridian, it is 0 o'clock, sidereal time; when the first point of Aries has moved 15° west of the meridian, it is 1 o'clock, sidereal time; when it has gone 30° west, it is 2 o'clock; 90°, 6 o'clock; 180°, 12 o'clock: 270°, 18 o'clock. Astronomers generally go on from 12 o'clock to 13 o'clock, 14 o'clock, &c., up to 24 o'clock, when a new day commences.

198 Hence the sidereal time at which a star crosses the meridian is evidently the right ascension of the star expressed in time; for, as we have shown above, the right ascension of a star, expressed in time, is the number of hours, minutes, and seconds that elapse between the transit of the first point of Aries and the transit of the star; therefore, when the star is crossing the meridian, the first point of Aries is that number of hours, minutes, and seconds past the meridian,—i. e., the sidereal time is that number of hours, minutes, and seconds past 0 o'clock.

199 *Solar Time.*—Solar time is time measured by the Sun's motion, in the same manner as sidereal time by the motion of the first point of Aries. The interval of time in which the Sun completes his revolution is called a solar day, the twenty-fourth part of it a solar hour. Also the solar day commences when the Sun comes on the meridian.

200 Hence sidereal and solar time differ in two respects: *First.* The sidereal and solar days commence at different instants of time, for the Sun and the first point of Aries never cross the meridian together, except at the vernal equinox, when the Sun coincides with the first point of Aries. We have already explained the nature of the Sun's proper motion, which carries him backwards among the stars (i. e., contrary to the apparent motion of the heavens) about 1° each day, which corresponds to 4′ of time. Let P and Q, fig. 48, represent the poles; P E Q G, the meridian; E A G, the equator; A, the first point of Aries; S, the Sun; P S S′ Q, the polar circle in which the Sun is, intersecting the equator at S′. Then S and S′ will cross the meridian at the same instant, and therefore, with respect to solar time, we may consider the Sun to be at S′; in fact, it will be 0 o'clock, solar time, when S′ comes on the meridian, and the solar day will be the interval of time in which S′ completes its revolution.

Fig. 48



201 The arrow in the figure shows the direction of the apparent diurnal rotation of the heavens, which carries A and S′ round and through 15° every hour. But we must remember that, as the year goes on, the point S′ is con-

tinually moving backwards, (i. e., contrary to the arrow,) in consequence of the Sun's proper motion, completing the whole 360° in a year. The distance of S' from A is therefore continually increasing at the rate of about 1° daily; for 1° is very little greater than the 365th part of 360°, and therefore the daily increase of the distance, $A\,S'$, is about 1° daily.

202 About the third week in March, S' will coincide with A, and therefore, since both points cross the meridian together, it will be 0 o'clock, sidereal time, at the same instant that it is 0 o'clock solar time.

In a quarter of a year afterwards,—i. e., in June, $A\,S'$ will be 90°, or 6^h, in time; therefore A' will cross the meridian 6 hours before S'; in other words, it will be 6 o'clock, sidereal time, when it is 0 o'clock, solar time.

In September $A\,S'$ will be 180°, or 12^h in time; therefore it will be 12 o'clock sidereal time, when it is 0 o'clock solar time.

In December $A\,S'$ will be 270°, or 18^h in time; therefore it will be 18 o'clock sidereal time, when it is 0 o'clock solar time.

203 *Secondly.* Solar time is longer than sidereal. For since S' moves back about 1° every day, it will cross the meridian about 4^m late every day—i. e., 4^m later than it would do if it remained stationary in the heavens. It is clear, therefore, that the solar day will be about 4^m longer than the sidereal day. This may also be shown by considering what has just been stated—namely, that in a quarter of a year (i. e., 90 days in round numbers) after the equinox, it will be 6 o'clock, sidereal time, when it is 0 o'clock, solar time. Hence 90 days, solar time, are equivalent to 90 days and 6 hours, sidereal time; and therefore, taking the 90th part of 90 days and 6 hours, which is 1 day and 4 minutes, it appears that 1 day solar time is equivalent to 1 day and 4 minutes sidereal time—i. e., the solar day is about 4^m longer than the sidereal day.

204 *Apparent and Mean Solar Time.*—Solar time, defined as above by the Sun's motion, is not regular and uniform as sidereal time is. This arises from two causes—first, the oval form of the orbit in which the Earth moves round the Sun, which makes the Earth move sometimes quicker and sometimes slower, and therefore renders the apparent annual motion of the Sun irregular; and, secondly, the obliquity of the ecliptic to the equator makes the interval between two successive transits of the Sun across the meridian longer at the solstices and shorter at the equinoxes.

From both causes, the day shown by the Sun's motion is sometimes longer and sometimes shorter. It would, of course, be very inconvenient to employ the Sun's motion, subject to such irregularities, to mark time; and yet, for civil purposes, it would be quite as inconvenient to use sidereal time—e. g., in March it is two hours past mid-day at two o'clock, sidereal time; in July, it is two hours before midnight at two o'clock, sidereal time.

205 To obviate these inconveniences, we use for civil purposes, and in astronomical observations also, what is called ***mean solar time***, which is nothing but regulated solar time, the irregularities of the Sun's motion being allowed for and corrected. The word 'mean' signifies 'average;' the length of the mean solar day is the average length of the solar day: which is determined as follows:—

It is found by observation that the backward motion of the Sun, or rather of the point S', fig. 31, in the interval between two successive transits of the Sun across the meridian, is, taking its average or mean length, not quite 1°, but $59'\ 8''$, (we omit fractions of $1''$;) on some days it is greater than this, and on some days less; but its average length in a great number of days is $59'\ 8''$. Therefore, considering the average motion of the Sun only, and supposing the Sun to be on the meridian now, it is clear that the heavens must turn round $59'\ 8''$ more than a complete revolution—i. e., $360°\ 59'\ 8''$, before the Sun comes on the meridian again; in other words, the average or mean length of the solar day corresponds to a revolution of the heavens through $360°\ 59'\ 8''$, which, expressed in sidereal time, at 15° per hour, $15'$ per minute, $15''$ per second, amounts to $25^h\ 3^m\ 56\frac{1}{2}^s$. Hence it appears that the mean or average solar day consists of $24^h\ 3^m\ 56\frac{1}{2}^s$ sidereal time, and is therefore longer than the sidereal day by 3 minutes $56\frac{1}{2}$ seconds.

206 A well-regulated clock shows mean solar time; a sun-dial shows the actual irregular solar time, or, as it is called, *apparent* solar time.

207 *Equation of Time.*—The equation of time is the number of minutes and seconds that must be added to or subtracted from the apparent solar time, or the time shown by a sun-dial, in order to make it equal to, or, as it is said, to *equate* it to the mean solar time, or the time shown by a clock. The equation of time is sometimes greater and sometimes smaller; sometimes it is *additive*—i. e., to be added to the apparent time—and sometimes it is *subtractive.* It is given in the almanac, often in columns headed 'Sun too slow,' 'Sun too fast,' or 'Clock after Sun,' 'Clock before Sun.' Thus, in White's *Ephemeris* for 1849, on March 30, in the column headed 'Clock before ⊙,' we find $4^m\ 33^s$; which means, that $4^m\ 33^s$ must be subtracted from the apparent time to get the mean time. Again, on November 4, in the column headed 'Clock after ⊙,' we find $16^m\ 16^s$, which means that $16^m\ 16^s$ must be added to the apparent time to get the mean time.

CHAPTER IV.

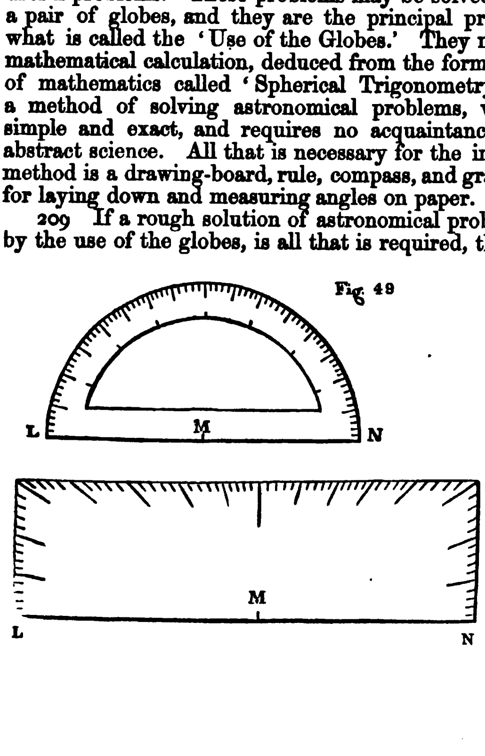
METHOD OF SOLVING ASTRONOMICAL PROBLEMS BY CONSTRUCTION ON PAPER.

I. *Instruments necessary.*

WE have now sufficiently explained the meaning of astronomical terms to enable us to proceed to the solution of a variety of interesting and useful problems. These problems may be solved in a rough way by means of a pair of globes, and they are the principal problems usually treated of in what is called the 'Use of the Globes.' They may be solved accurately by mathematical calculation, deduced from the formulæ and rules of that branch of mathematics called 'Spherical Trigonometry.' We shall now explain a method of solving astronomical problems, which is at the same time simple and exact, and requires no acquaintance with the technicalities of abstract science. All that is necessary for the immediate application of this method is a drawing-board, rule, compass, and graduated circle, or protractor, for laying down and measuring angles on paper.

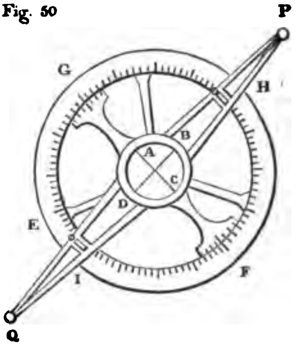
209 If a rough solution of astronomical problems, such as that attainable by the use of the globes, is all that is required, these instruments may be of a very ordinary description; a table will serve in place of a drawing-board, and a common graduated ruler or brass semicircle will answer perfectly well for laying down and measuring angles. See fig. 49.

Fig. 49



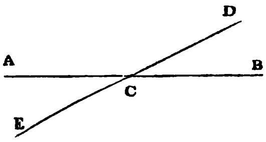
If, however, accuracy is required, a good flat drawing-board must be procured, and the paper must be strained upon it, having been previously damped; the ruler must be perfectly straight, and should be made of hard metal; the points of the compass must be fine, and one leg ought to have an adjusting-screw, for the purpose of opening the compass with great exactness to any required distance; and, lastly, the circle or protractor, which is shown in fig. 49, ought to be capable of measuring an angle accurately to a minute by means of a Vernier, (which we shall presently speak about.) Respecting the protractor, we may observe here that it consists of a graduated circle, E F G, fig. 50, and an arm P H I Q, which turns round about the centre of the graduated circle, carrying Verniers at G and F; the centre is marked by the intersection of two fine lines, A C and B D, generally drawn on a small piece of plate-glass, A B C D, fixed in the middle of the arm; at P and Q are two fine points, which may be pressed down on the paper so as to mark it slightly; the line joining these points passes through the centre of the circle.

Fig. 50



210 The use of this instrument is as follows:—Suppose it is required to draw a line through the point C, making an angle of 30° with the line A B. Place the protractor on the paper with the centre (i. e., the intersection of the two lines drawn on the piece of glass) exactly on the point C; bring the points (i. e., P and Q, fig. 50) exactly over the line A B; then, by looking at the graduations on the circle, turn the arm through 30°; this being done, mark the paper by pressing down the points, and suppose E and D to be the two marks; then join E and D, and E D will be the required line, making an angle of 30° with A B.

Fig. 51



In like manner we might apply the instrument to measure the number of degrees and minutes contained in any angle drawn upon the paper.

211 This instrument, if well made, is capable of great accuracy. We may observe that, by always using the two points and reading off at the two Verniers, we may entirely get rid of any error there may be, either in the position of the centre, or in placing the centre on the point C, fig. 51; but we have not space to say anything on this head.

212 In using the simple instruments shown in fig. 49, we have only to place the point M, which is the centre of the graduations, upon C, fig. 51, and the line L N on A B; then by looking at the graduations we shall see what angle C D makes with C B.

The method we are about to explain has the advantage of giving, with great facility, and without supposing any knowledge of Trigonometry, the means of solving astronomical problems much more accurately than could be done by means of globes. It also gives very simply the various mathematical formulæ employed in astronomy.

II. *Of Spherical Triangles.*

213 We must say a few words, before we proceed, in order to explain what a spherical triangle is, and what its several parts represent. In the same way that an ordinary or plane triangle is formed by three straight lines drawn on a plane surface, and meeting at three angular points, so a spherical triangle is formed by three arcs of great circles drawn on a spherical surface, and meeting in three angular points.

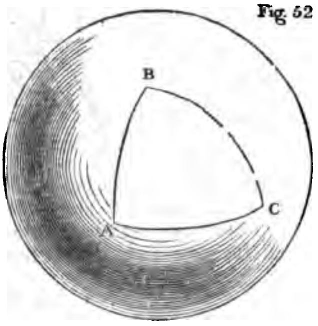
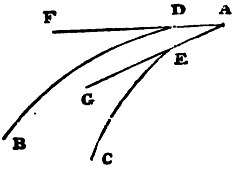


Fig. 52

214 Fig. 52 represents a spherical surface, with a spherical triangle, A B C, drawn on it; A B, B C, and C A represent arcs of great circles; they are called the *sides* of the spherical triangle. The angles of this triangle show the inclinations of the three sides to each other at their respective points of intersection; but we must explain more fully what the angles of a spherical triangle are.

215 *Angles of a Spherical Triangle.*—Let A B and A C, fig. 53, be any two circular arcs, or other curved lines meeting at a point, A; then we cannot speak generally of the inclination of the arc A B to the arc A C, as we could do if they were straight lines, because, being curves, they are differently inclined to each other at different parts. But we may speak of the inclination of these two curves to each other at the point A; for take two points, D and E, on A B and A C respectively, very near A, so near that the portions A D and A E may be too small for their curvature to be sensible, and we may regard them as two very small straight lines. These two lines make a certain angle with each other, whatever it may be, and that angle is the angle at which the two curves meet each other at the point A. This sufficiently explains what we mean by the angles of a spherical triangle.

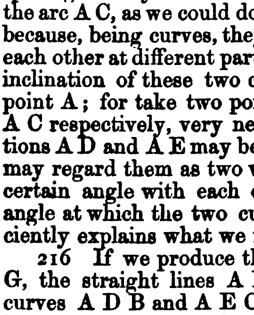
Fig. 53



216 If we produce the two small lines A D and A E to any points, F and G, the straight lines A F and A G are respectively coincident with the two curves A D B and A E C, in the immediate vicinity of the point A; these lines are therefore said to *touch* the curves at A; A F is said to be the *tangent* to the curve A D B at the point A, and A G is said to be the *tangent* to the curve A E C at the point A.

217 Hence, the angle which the two tangents make with each other is the same thing as the angle which the two curves make with each other at the point A.

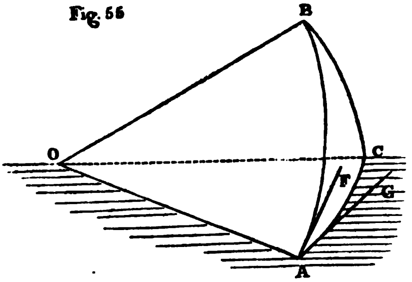
Fig. 54



218 If A F, fig. 54, be the tangent at any point, A, of a circle, whose centre is O, it is easy to see that A F is perpendicular to the radius A O; for if A D be an extremely small portion of the circumference, so small that we may consider it a straight line, the tangent A F is simply A D, produced to any point F; now since, in describing a circle, the point of the compass always moves perpendicularly to the radius, A D must be perpendicular to A O, and therefore A F is so also.

219 It is important to remember, that the tangent at any point of a circle is perpendicular to the radius or line drawn from that point to the centre. We may also observe, that the tangent always lies in the same plane as the circle.

Fig. 55



220 *A Spherical Triangle completely represents a Solid Angle.*—Let A B C, fig. 55, be a spherical triangle, O the centre of the spherical surface, on which the triangle is drawn, O A, O B, O C, the radii drawn to the angular points A B C. Then A B is a circular arc described with O as centre; therefore A B represents or measures the angle A O B, which the two radii A O and B O make with each other—i.e., the number of degrees, minutes, and seconds in A B, and in the angle A O B are the same, as has been fully explained in Chapter II. In like manner the circular arc B C shows the angle B O C, which the two radii drawn from B and C make with each other, and the circular arc C A, the angle C O A, which the two radii drawn from C and A make with each other.

221 Again, if we draw from A the two lines A F and A G, touching the circular arcs A B and A C at A, the angle F A G which these two tangents make with each other, is the same thing as the angle A of the spherical triangle. But the angle F A G also shows the inclination of the two planes A O B and A O C to each other, as we may prove in the following manner.

222 By the plane A O B, we mean the plane in which the two radii, A O, B O, the circular arc A B, and of course the tangent A F, all lie; by the plane A O C, we mean the plane in which A O, C O, the circular arc A C, and the tangent A G, all lie. A O is the line of intersection of these two planes, and the tangents A G, A F, are perpendicular to the radius A O. Now the angle at which two planes are inclined to each other is shown by drawing from a point in their line of intersection, a line in each plane perpendicular to the line of intersection. That this is the case is easily seen, by marking with a knife a line E F, fig. 56, on a piece of card A B C D, and drawing a perpendicular line R P Q in pencil: then turn the two parts A E F D and B E F D about the cut line E F, so as to make them make an angle with each other, as in fig. 57; and it will be immediately seen, that, at whatever angle we incline

Fig. 56

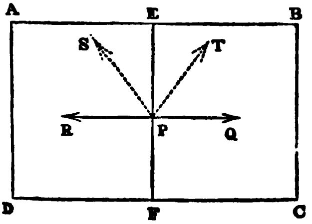
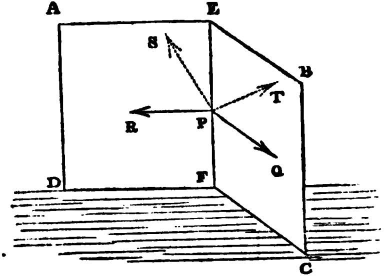


Fig. 57



the two planes A E F D and B E F C to each other, the two lines R P and P Q will always make the same angle with each other. But if we draw two lines, P S and P T, not perpendicular to E F, the angle these two lines make with each other will always be less than the angle at which the two planes are inclined.

223 Hence, returning to fig. 55, it is manifest, that the angle F A G, or, what is the same thing, the angle A of the spherical triangle, shows the angle at which the two planes A O B and A O C are inclined to each other. In like manner we may show that the angle B shows the angle at which the two

planes B O A and B O C are inclined to each other, and the angle C shows the angle at which the two planes C O A and C O B are inclined to each other.

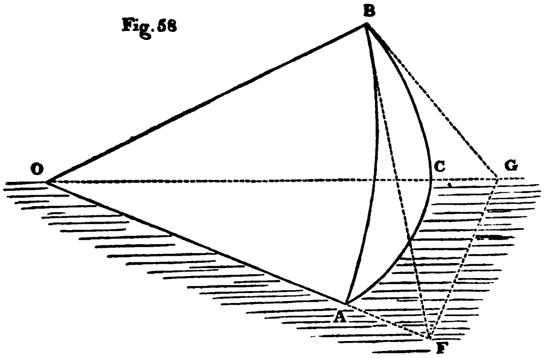
224 The triangular point O, which is formed by the meeting of the three planes A O B, B O C, C O A, is called a *solid angle*, the three planes are called the *planes, or faces, of the solid angle*, and the three lines O A, O B, O C, are called its *edges*.

225 Hence, it appears, that the spherical triangle A B C represents, in all its parts, the solid angle O, which is formed by drawing radii from the angles A B C to the centre O—namely, the three sides of the spherical triangle, A B, B C, C A, represent respectively the three angles, A O B, B O C, C O A, which the edges, O A, O B, O C, of the solid angle make with each other; and the three angles, A, B, C, represent the angles at which the planes A O B, B O C, C O A, of the solid angle are inclined to each other.

III. *Method of representing the different parts of a Spherical Triangle on Flat Paper.*

226 *First Construction.*—Let A B C, fig. 58, be the spherical triangle, O the centre of the sphere; draw B F, a tangent to the circular arc B A, at B, and B G a tangent to the circular arc B C at B; let these tangents meet O A and O C produced at F and G respectively, and join F G. Then, as we have explained, the angles B O F, B O G, and F O G, are shown by the sides of the spherical triangle—namely, B A, B C, and A C respectively; also the angle B of the spherical triangle is the same thing as the angle F B G.

Fig. 58



Now let us conceive the solid figure O B G F to be formed of four triangular planes of thin board or card—namely, B O F, B O G, B G F, and F O G, fastened together by hinges along the edges O F, O G, and F G, and by a clasp of some kind at B, so that, if the clasp at B be unfastened, the plane O B F may be turned about the edge O F, the plane O B G about the edge O G, and the plane B G F about the edge F G. This being supposed, let the clasp at B be unfastened, and let the planes O B F, O B G, and B F G, be turned about the hinged edges, until they all form one plane with O G F, so that the four planes may be laid flat upon the table, as is represented in fig. 59, where O F G, G B F, and O B′ F, and O B″ G, represent respectively the planes O F G, G B F, O B F, and O B G, in fig. 58.

227 Hence, fig. 59 represents on flat paper the three sides and one angle of the spherical triangle—namely, the angles F O B′, F O G, and G O B″, show the sides A B, A C, and C B respectively, and the angle G B F shows the angle B. It is important to observe that the angles O B′ F, and O B″ G, fig. 59, being respectively equal to O B F and O B G, fig. 58, are right angles, that the lines O B′ and O B″, fig. 59, being each equal to O B, fig. 58, are of equal length, that G B″ and G B, fig. 59, being each equal to G B, fig. 58, are

of equal length, and that the same is true of F B′ and F B, fig. 59, which are each equal to F B, fig. 58.

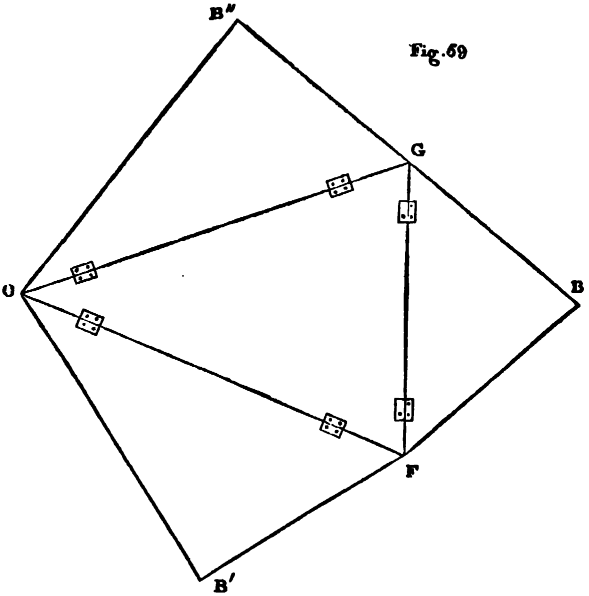


Fig. 59

228 We have, therefore, the following construction on flat paper for representing the three sides and one angle of a spherical triangle, whose angles we shall denote by A B and C, and the sides respectively opposite those angles by the small letters *a b c*.

Choosing a point O on the paper, draw the lines O B′, O F, O G, and O B″, fig. 60, making angles with each other equal to the three sides *a b* and *c*

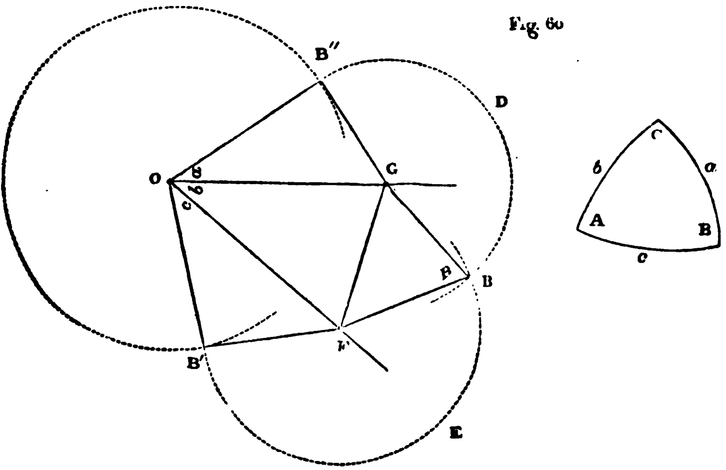


Fig. 60

of the spherical triangle—i. e., the angles *a b* and *c* at O, contain respectively the same number of degrees, minutes, and seconds, as the sides *a b* and *c* of the spherical triangle. Putting one point of the compass at O, strike off O B′ and O B″ equal to each other; draw B″ G perpendicular to O B″, and B′ F perpendicular to O B′, to meet the lines O G and O F, at G and F; with G as centre and G B″ as radius, and with F as centre and F B′ as radius, describe two circular arcs B″ D B and B′ E B, intersecting each other at the point B, and join B G and B F: then the angle G B F so formed, is equal to the angle B of the spherical triangle.

229 This construction will enable us to solve any astronomical problem in which we are concerned, with the three sides and one angle of a spherical triangle. We shall now give another construction for representing the two other angles of the spherical triangle, A and C.

230 *Second Construction.*—As before, let A B C be the spherical triangle, and O the centre of the sphere; draw the lines B E perpendicular to O A, and B F perpendicular to O C; in the plane O A C, draw E D perpendicular to O A, and F D perpendicular to O C, to meet in D, and join B D. The two planes B E D and B F D, being thus made perpendicular to the plane O A C, their line of intersection B D will also be perpendicular to the plane O A C, and therefore to the two lines E D and F D, which lie in that plane: the two angles B D E and B D F, are therefore each right angles.

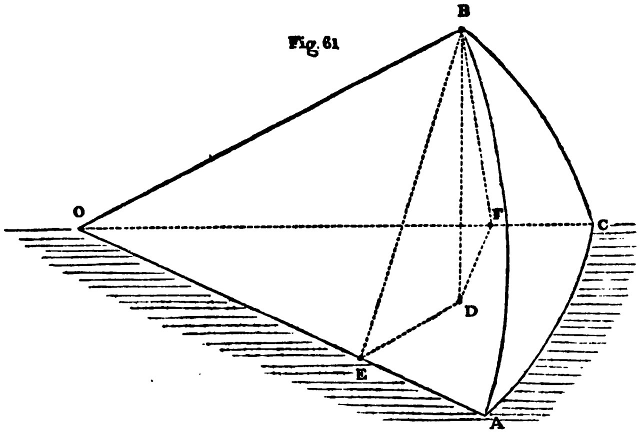


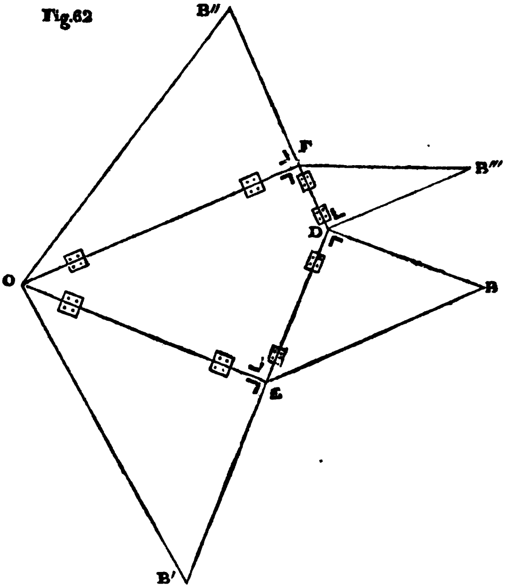
Fig. 61

In this construction E B and E D are perpendicular to O A, the line of intersection of the two planes O A B and O A C, and therefore, as we have previously explained, the angle B E D shows the inclination of these two planes to each other, or, what is the same thing, the angle A of the spherical triangle; the angle B E D is therefore equal to the angle A; and in like manner, we may show that the angle B F D is equal to the angle C, of the spherical triangle.

231 Now, just as in the former construction, let us suppose the solid figure O B E D F to be formed by four triangular planes, O B E, O B F, B E D, B F D, hinged at their lower edges to the quadrangular plane O F D E, and fastened at B by a clasp. Let the clasp be unfastened, and the four triangular planes turned about their hinged edges, until they form one plane with the quadrangular plane O F D E, so that five planes may be laid flat on the table, as is represented in fig. 62, where O F D E is the quadrangular plane, and O F B″, O E B′, D F B‴, D E B, the four triangular planes—namely, O F B, O E B, D F B, D E B, in fig. 61.

232 Hence, fig. 62 represents on flat paper the three sides and the other two angles of the spherical triangle—namely, the angles at O show the sides of the spherical triangle, just as in the former construction, and the angles D E B, D F B‴, show the two angles A and C.

Fig. 62

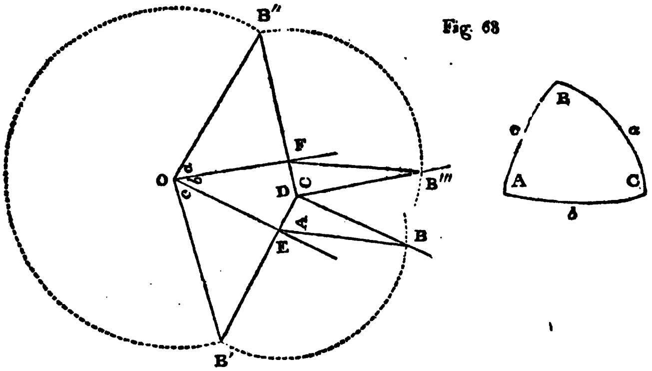


233 It is important to observe, as before, that angles marked thus ∟, in figure 62, are right angles, because they are respectively equal to angles in fig. 61, which we know to be right angles. Also, as before, O B′ and O B″ are equal, F B″ and F B‴ are equal, D B‴ and D B are equal, and E B and E B′ are equal, each pair of lines being equal to O B, F B, D B, and E B, respectively, in fig. 61.

234 We have, therefore, the following construction on flat paper for representing the three sides *a b* and *c*, and the other two angles A and C of the spherical triangle.

Draw O B′, O E, O F, and O B″, fig. 63, making, as before, angles, *a b c*, with each other; make O B″ equal to O B′; draw B″ F perpendicular to O F, and B′ E perpendicular to O E, and produce those perpendiculars to meet in D; draw D B‴ perpendicular to F D, and D B perpendicular to E D; with centre F and radius F B″, and with centre E and radius E B′ describe two circular arcs, cutting the perpendiculars last drawn in B‴ and B, and join B‴ F and B E; then the angle B E D will be equal to the angle A of the spherical triangle, and the angle B‴ F D will be equal to the angle C.

Fig. 63



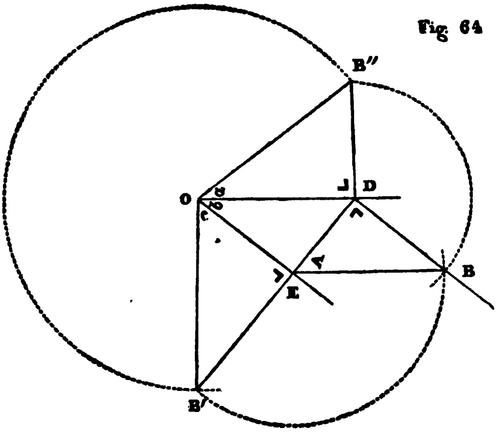
235 This construction is of considerable importance, and solves a great number of astronomical problems, only in practice it is much simpler than it appears to be here, stated as it is in all its generality.

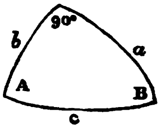
This construction is also of importance, because it gives immediately all the mathematical formulæ of spherical trigonometry used in the most exact astronomical calculations.

236 *Application of the Second Construction to Right Angled Spherical*

Triangles.—When one of the angles of a spherical triangle is a right angle or 90°, it is called a right angled spherical triangle. Suppose C to be a right angle in the second construction; then B''' F, fig. 62, is perpendicular to F D, and therefore, since B''' D is also perpendicular to F D, the two lines B''' F and B''' D coincide; in other words, the points F and D coincide. Hence the construction becomes what is represented in fig. 64, in which O B' and O B'' are equal, D B'' and D B are equal, E B' and E B are equal, and the angles thus marked, ⌞, are right angles.

Fig. 64

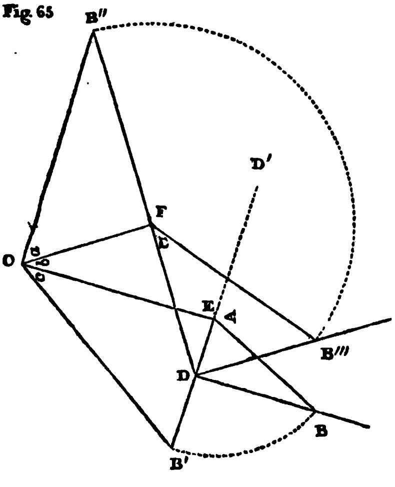




237 Hence we have the following simple construction for a spherical triangle, one of whose angles, C, is 90°.

Draw from O lines, as before, fig. 64, making the angles *a b c* with each other; make O B'' equal to O B', draw B'' D perpendicular to O D, and B' E perpendicular to O E, which two perpendiculars produced will always meet at a point D of the line O D, when the angle C is 90°; with radius D B'' and centre D, and with radius E B' and centre E, describe two circular arcs intersecting at B, and join B D and B E; then the angle B D E will be 90°, and the angle B E D will be equal to the angle A of the spherical triangle.

Fig. 65



238 This construction solves every case of right angled spherical triangles, and therefore, as will appear, a great number of practically useful astronomical problems. We might easily show that this construction gives immediately what are known as Napier's Rules, and obviates the necessity of the use of these rules, which is often very troublesome.

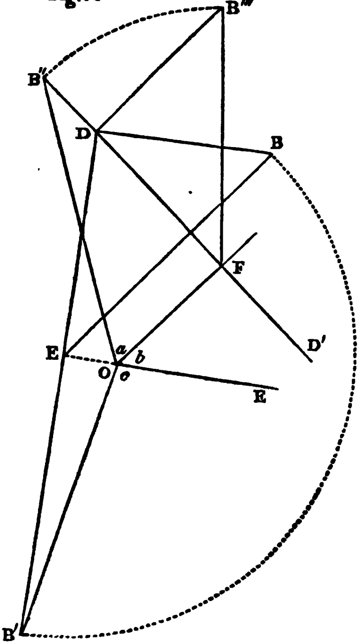
239 *Observations respecting the Second Construction.*—It sometimes happens, in making the second construction, that one of the two perpendiculars, B'' F and B' E, when produced, meets the other in the manner shown in fig. 65, in which case the point D lies between E and B', or, it may be, even beyond B' in E B' produced. In this case, the construction is precisely the

same as before; we must draw D B‴ perpendicular to F D, F B‴ equal to F B″, and D B perpendicular to E D, making E B equal to E B′. There is, however, a caution necessary respecting the angle A—namely, the angle B E D is not A, but B E D′ is, where E D′ is D E produced. It is therefore necessary to make the following statement respecting the angles A and B.

240 In all cases, wherever the point D may fall, the angle A is the angle which the line E B makes with the perpendicular B′ E, *produced beyond* E—i. e., the angle contained between E B and the *produced part* of the perpendicular; and, in like manner, the angle C is the angle which the line F B‴ makes with the perpendicular B″ F produced beyond F—i. e., the angle contained between F B‴ and the produced part of the perpendicular. No mistake can be committed if it be remembered that the angles A and C are those made, not by the perpendiculars, but by the perpendiculars produced.

241 When any of the angles *a b c*, as for instance *a*, happens to be greater than 90°, the point E will fall on the other side of the point O, as is shown in fig. 66. In this case, the construction is the same as before, without the least alteration, and the same rule holds with reference to A and C. A is the angle B E D which is contained between E B and the produced part E D of the perpendicular B′ E, and C is the angle B‴ F D′, which is contained between F B‴ and the produced part F D′ of the perpendicular B″ F.

Fig. 66



242 We have been particular in discussing the second construction on account of its importance, but no mistake can be made if the following points, which apply to all cases, be remembered.

O B′ = O B″, F B″ = F B‴, D B‴ = D B, E B = E B′;
O F B″, O F D, O E B′, O E D, F D B‴, and E D B, are right angles;
The three angles at O are the sides of the spherical triangle;
The angle of the spherical triangle which is opposite the side B′ O E is the angle contained between F B‴ and B″ F produced;
The angle opposite the side B″ O F is the angle contained between E B and B′ E produced.

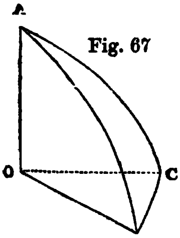


Fig. 67

243 *Observations respecting a spherical triangle, two of whose sides are each* 90°.—When this is the case, as in fig. 67, where *b* and *c* are each 90°, it is important to remember, 1st. that *a* and A are equal (i. e., they contain the same number of degrees, minutes, and seconds,) and 2ndly, that B and C are each right angles. To prove this, let O be the centre of the sphere, and join O A, O B, and O C; then, since *c* is 90°, A O B is a right angle, and since *b* is 90°, A O C is a right angle; therefore A O, being perpendicular to O C and O B, it is manifest that

the planes A O B and B O C are at right angles to each other, and that the same is true of the planes A O C and B O C; wherefore the angles B and C, which show the inclinations of these planes to each other, are right angles; also O C and O B being at right angles to the intersection O A of the two planes O A B and O A C, the angle C O B (which equals a) shows the inclination of these two planes—i. e., the angle A; therefore a and A are equal.

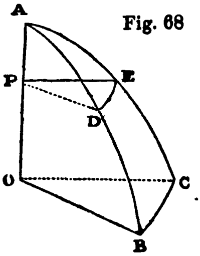


Fig. 68

244 It is also important to remember that, if from any point P of O A we draw P E and P D perpendicular to O A, as is shown in fig. 68, and describe the circular arc D E, (which is a portion of a small circle described about the pole A,) then the proportion of the arc D E to the arc B C is the same thing as the proportion of the line P D to the line O B. This will become evident if we consider the arcs C B and E D, to be described by the points B and D, when we turn the plane O A D B about the axis O A; for then if P D is half O B, the point D will only move half as fast as the point B, and therefore the arc E D will be always half of the arc B C; in the same manner, if P D be one-third of O B, B will move three times faster than D, and therefore C B will be three times E D, and so on. In whatever proportion, therefore, P D is less than O B, the arc E D will be less than the arc C B in the same proportion. See Chapter II.

Having now said enough of spherical triangles, we shall proceed to the solution of astronomical problems.

IV. *Solution of various Astronomical Problems.*

245 In the solution of the following problem, it will be necessary to have an Ephemeris, or almanack, with astronomical tables. White's *Celestial Atlas,* which only costs a shilling, and is published regularly every year, will answer every purpose.

Problem I.

To find the Time of Sunrise on any given day of the Year.

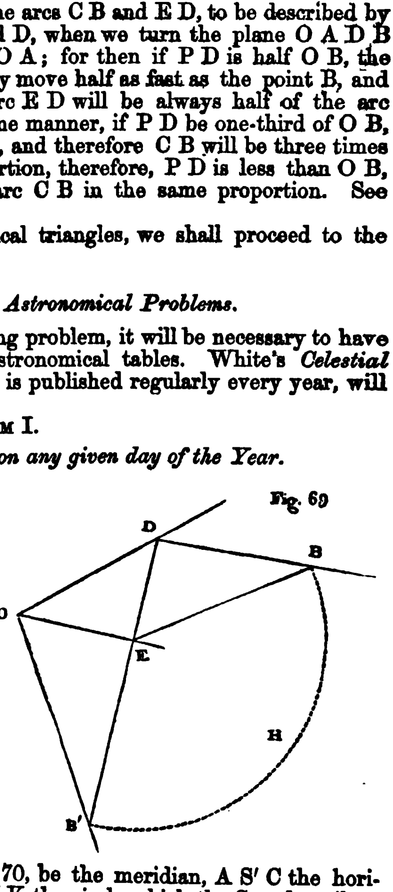
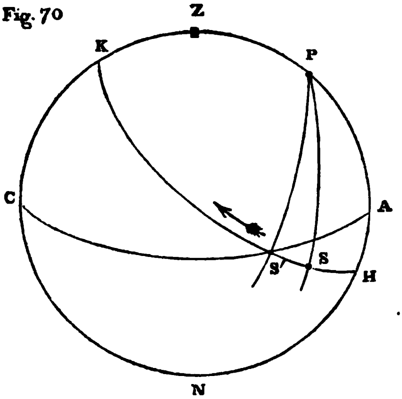


Fig. 69

246 *Solution.*—Draw a line O B′, of any convenient length, fig. 69, and another O E, making the angle E O B′ equal to the Sun's north polar distance, which is given in the Ephemeris; and draw B′ E perpendicular to O E. Draw O D, making the angle D O E equal to the latitude of the place, (which is of course known,) and meeting B′ E produced at D. Draw D B perpendicular to E D, to meet a circular arc B′ H B, described with E as centre. Measure the angle D E B, and convert it into time, allowing one hour for every 15°; then that time is the hour of sunrise, as shown by the sun-dial.

247 *Proof.*—Let K Z P A H, fig. 70, be the meridian, A S′ C the horizon, P the Pole, S the Sun, and H S S′ K the circle which the Sun describes, (in consequence of the rotation of the heavens about P,) crossing the horizon at S′. When the Sun is at K, it is midday; when at H, midnight; and when he comes to S′ he rises; therefore the angle A P S′, being described about P by the polar circle P S in the interval between midnight and sunrise, is, when expressed in time at 15° per hour, the number of hours, minutes, and

Fig. 70



seconds between midnight and sunrise, or, what is the same thing, the hour of sunrise.

Now this angle is the angle at P in the spherical triangle A S′ P, in which triangle the angle at A is 90°, the side P S′ is the Sun's polar distance, and the side P A is the latitude of the place (see art. 194.) Hence, employing the *second construction*, (as it applies to a right-angled triangle, art. 236,) supposing A S′, A P, and P S′ to be *a*, *b*, and *c*, respectively, and therefore the angle at P to be A, we obtain immediately the above solution.

248 *Example.*—On the 2nd of May, 1849, at what hour will the Sun rise in London?

Looking in White's *Celestial Atlas* for 1849, we find—

Page 47. Latitude of London, 51° 31′.

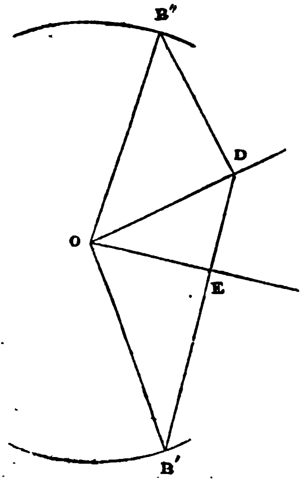
Page 10. Sun's declination 15° 26′ north, and therefore polar distance 74° 34′.

Therefore in fig. 69 we must make E O B′ 74° 34′, E O D 51° 31′, which if we do, we shall find the hour of sunrise to be twenty-nine minutes past four, as shown by the sun-dial.

249 It appears by the Ephemeris, that the Sun is about three minutes after the clock on the 2nd of May, therefore the time of sunrise by the clock will be thirty-two minutes past four.

250 If we examine the tables of the hours of sunrise and sunset in the Ephemeris, we shall find that twelve o'clock is not half way between sunrise and sunset; the reason of this is, that twelve shown by the clock, is not the same as twelve shown by the dial. Twelve, as shown by the dial, would be exactly half-way between sunrise and sunset, only for the motion of the Sun. In fact, in working out the above problem, we have for simplicity supposed the Sun to remain fixed in the heavens during the day. This is not true, and therefore our result is slightly erroneous.

Fig. 71



251 We shall presently show that, in consequence of the refraction of light by the atmosphere, heavenly bodies appear to rise a little before, and to set a little after, they actually come on the horizon.

Problem II.

To find at what Point of the Compass the Sun rises.

252 *Solution.*—Draw the lines O B′, O E, and O D, (fig. 71,) exactly as in Problem I., making E O B′ equal to the Sun's polar distance, E O D equal to the latitude of the place, and B′ D perpendicular to O D. Draw D B″ perpendicular to O D, to meet a circular arc, B′ H B″, described about O as centre, at B″ Measure the angle D O B″, and the result will be the Sun's azimuth at rising, which, as we have explained in the previous chapter, shows the point of the compass at which he rises; for example, if D O B″

be 0, the Sun rises in the north; if 45°, in the north east; if 90°, in the east, and so on.

253 *Proof.*—In fig. 70, A S′ is the Sun's azimuth at rising, and A S′ is the third side of the right angled spherical triangle, A P S′, considered in Problem I.; therefore, employing the *second construction* as applied to a right angled triangle, we find the azimuth in the manner just stated.

254 By means of this problem, or rather, by a mathematical calculation equivalent thereto, the *variation* of the compass is often found at sea. The magnetic needle does not point truly to the north; the error is called the variation of the compass; and it is different at different points of the Earth's surface. It is, of course, necessary for the navigator to determine this error, and how it changes as he sails over the ocean; this he does by observing with the compass at what point the Sun rises,—i. e., the Sun's azimuth at rising; he then, by means of a mathematical calculation equivalent to Problem II., finds what the Sun's azimuth ought to be, and takes the difference between the result and the azimuth observed by the compass; which difference is manifestly the error or variation of the compass.

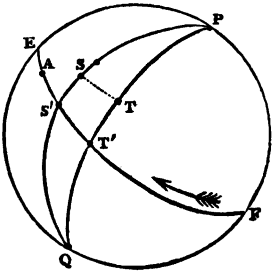
Problem III.

On a given Day of the Year, to find at what Hour any given Star crosses the Meridian.

255 *Solution.*—Look in the *Ephemeris* for the Sun's right ascension and that of the star; subtract the former from the latter, and the result will be the hour (i. e., the number of sidereal hours, minutes, and seconds, after mid-day by the dial) at which the star crosses the meridian.

If the Sun's right ascension should happen to be greater than that of the star, add 24^h to the latter before subtracting.

Fig. 72



256 *Proof.*—Let S, fig. 72, be the Sun; T, the star; E S′ T′ F, the equator; P S S′ Q and P T T′ Q being respectively the declination or polar circles of the Sun and star. Then S′ T′, reduced to time, is evidently the number of hours, minutes, and seconds between the transits of S and T; but if A be the first point of Aries, A S′ and A T′ are the right ascensions of S and T, and therefore S′ T′ is the difference between the right ascension of the star and that of the Sun. Hence the truth of the solution is manifest.

257 By adding 24^h to the right ascension of a heavenly body, we do not alter its position on the celestial sphere, since 24^h corresponds to 360°,—i. e., a complete revolution. We may therefore, if we please, add 24^h to the star's right ascension, should it happen to be less than that of the Sun, in order to make the subtraction of the former from the latter possible.

258 *Examples.*—At what hour does Arcturus cross the meridian on the 25th of September, 1849?

Looking in the *Ephemeris* we find, omitting seconds:—

Right Ascension of Arcturus (α Bootes) . . .	14^h 9^m
Ditto of Sun, (September 25th, 1849) .	12^h 8^m
Difference,	2^h 1^m

Therefore Arcturus crosses the meridian 2^h 1^m after apparent noon.

259 We have taken here the Sun's right ascension at mean noon, on the 25th of September, which is given in the *Ephemeris*. A small correction is necessary in this, to allow for backward motion of the Sun in the interval between noon and the transit of the star.

260 To determine the same for the 25th of December, we have:—

Right Ascension of Arcturus + 24^h	38^h 9^m
Ditto of Sun (December 25th) . . .	18^h 16^m
Difference,	19^h 53^m

Therefore Arcturus crosses the meridian 19^h 53^m after apparent noon.

Problem IV.

To find at what Hour any given Star rises or sets on any specified Day of the Year.

261 *Solution.*—Precisely as in the case of the Sun, Problem I., find what time elapses between the rising of the star and its transit over the meridian; subtract this from the hour of the star's transit found by Problem III., adding 24^h to the latter if necessary; then the result is the hour of rising of the star.

To find the hour of setting, *add* instead of subtracting.

Example.—Supposing that we find by Problem I. that the star's transit takes place eight hours after its rising, and, by Problem III., that on the 1st of August the star crosses the meridian at 4 o'clock; at what hours does it rise and set?—

4 + 24 = 28	4
Subtract 8	Add 8
20	12

Therefore the star rises at 20 o'clock, (four hours before noon,) and sets at 12 o'clock.

262 The hours in these and the previous examples are sidereal hours, which are a little shorter than mean solar, or the ordinary civil hours. In round numbers, we may consider that a mean solar hour is ten seconds longer than a sidereal hour.

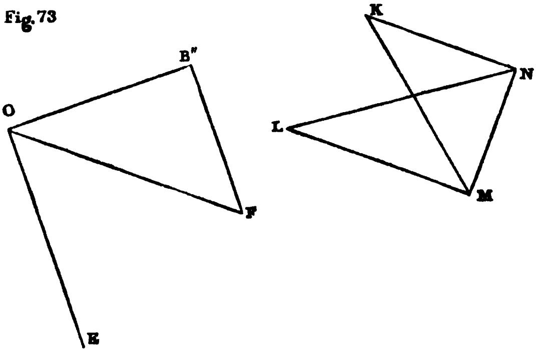
Problem V.

Having given the Right Ascensions and Declinations of two heavenly bodies, to find the Distance of one from the other, in degrees, minutes, and seconds.

263 *Solution.*—Find the polar distance of each body, (by subtracting its declination from 90°, or adding, if the body be south of the equator,) and the difference of the right ascensions in degrees, minutes, and seconds; and then make the following construction, fig. 73:—

Draw O B″ (of any length) and O F, making the angle B″ O F equal to the polar distance of one body; and draw B″ F at right angles to O B″; draw also L M equal to O B″, M N perpendicular to L M and L N, making the angle N L M equal to the polar distance of the other body; draw N K equal to B″ F, making the angle M N K equal to the difference of the right ascensions of the two bodies; and with centre F, and radius M K, and with centre O, and radius L N, describe two circular arcs intersecting at E; then

Fig. 73



the angle E O F being measured, gives the required distance between the two bodies, in degrees, minutes, and seconds.

264 *Proof.*—Let S and T, fig. 72, be the two bodies, and join S T by an arc of a great circle, which arc is the required distance between S and T; then, in the spherical triangle S P T, (P being the pole,) we have given the two sides P S and P T, which are the polar distances of S and T, and the angle S P T, which, as we have explained in the previous chapter, is the same thing as the arc S′ T′ (the difference of the right ascensions) on the equator, in degrees, minutes, and seconds. Hence we have given two sides and the included angle of a spherical triangle, and it is required to find the third side, S T. This can be done by means of the first construction; for, referring to it, suppose a c and B to be given: then, fixing upon any length we please for O B″, and therefore O B′, we may construct the two triangles, O B″ G and O B′ F, and so find the sides B″ G and B′ F, which are respectively equal to G B and F B; but B is known, and therefore, having found G B and F B, we can construct the triangle G B F, and so find G F: then, since we have thus determined O G, O F, and F G, we can construct the triangle O F G, and so find the angle b, which is the third side of the spherical triangle.

This is exactly what we have done in fig. 73, where the triangles L M N and K M N are the same as the triangles O F B′ and F B G in the first construction.

265 We might also solve this problem by the second construction, by supposing a b and C to be the given quantities, as follows:—

Draw O B″, O F, and O E, making a and b equal to the given polar distances, and B″ F at right angles to O B″, making O B″ of any length we please: draw F B‴, making C equal to the given difference of right ascensions: measure F B‴ equal to F B″, and draw B‴ D at right angles to B″ D: draw D E at right angles to O E, and produce it to meet a circular arc, described with O as centre and O B″ as radius, at the point B′: then E O B′, or c, the required third side of the spherical triangle, is found.

PROBLEM VI.

Having given the Latitudes and Longitudes of two places on the Earth's surface, to find the distance between them in miles.

266 *Solution.*—Proceed exactly as in Problem V., putting latitude for declination, and longitude for right ascension, and then convert the result into miles, by allowing 69½ miles for every degree, which will give the required answer.

267 It is not necessary to say anything to prove this, beyond observing that it is found by actual measurement, that a degree of a great circle on the Earth's surface is about 69½ miles long.

268 To solve this problem accurately, we ought to take into account the fact that the Earth's surface is not an exact sphere; without, however, going to such a degree of accuracy, this problem is very useful geographically.

269 We might insert here a great number of useful and important problems, but, as our space is limited, we shall not dwell longer on this subject now.

The problems given here are chiefly with a view of showing generally how the two constructions may be applied in astronomy.

CHAPTER V.

OPTICAL PRINCIPLES REQUISITE IN ASTRONOMY.

ALL astronomical observations are made through the medium of light, and by means of instruments whose construction mainly depends upon optical principles; it is therefore highly important for an astronomer to understand something of the science of optics, in order that he may be able to make the best use of his instruments, and avoid many errors into which he is likely to fall from ignorance of the laws which regulate the transmission of light. It will not be possible to devote sufficient space here to the full development of the principles of optics; all that we can do is, to explain those phenomena of light which have immediate reference to astronomy, and the laws upon which the construction and use of astronomical instruments depend.

We shall, in the first instance, state everything of practical importance relating to the transmission of light from luminous bodies: we shall then explain briefly the laws of reflection and refraction, the dispersion of light into different colours by refraction, and certain other points of practical importance; and lastly, we shall show how these laws enable us to construct instruments for ascertaining direction, and subdividing space with the greatest possible accuracy.

I. *Of the Transmission of Light from luminous bodies.*

271 *The transmission of light is not instantaneous.* The common and natural notion respecting the transmission of light is, that it comes from luminous bodies to the eye instantaneously; but this is not the case, though the almost inconceivable speed with which light travels is such, that it might be considered instantaneous, only for the extreme accuracy of astronomical observations, which require us to take account of the velocity of light.

272 The fact that light travels with a certain velocity was ascertained by the Danish astronomer, Römer (to whom we owe the invention of the transit instrument) in the following manner.

The planet Jupiter is accompanied by four satellites, which move round him in the same manner that the Moon does round our Earth, but in shorter periods. As these bodies revolve round their central planet, they appear to us to move backwards and forwards on each side of Jupiter, never receding far from him. Sometimes they manifestly pass in front of him, which is perceived by their casting shadows on his disk; and at other times they pass behind him, which is perceived by their sudden disappearance after they have come close to his disk. Sometimes also they are eclipsed by their entering the shadow which Jupiter casts. All this may be seen by means of an ordinary telescope.

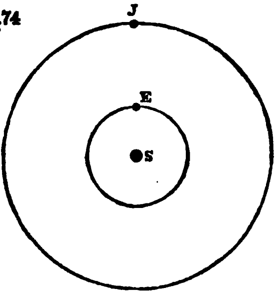
By watching these eclipses, occultations, and immersions, as they are called, of Jupiter's satellites, we may determine the rate at which they move round him. It is thus found that the following are their respective periods of revolution:—

The first satellite completes its revolution in about	1¾	days.
The second	3½	,,
The third	7	,,
The fourth	16¾	,,

It is important to notice the shortness of these periods, for upon that fact the discovery of the velocity of light in a great measure depended. In little more than a fortnight, it would be possible to ascertain these periods by watching the eclipses and occultations of the satellites; in fact, in that length of time the motion of the first satellite might be completely determined.

Having once made out these periods of revolution, we can of course always predict when the eclipses and occultations will occur during the lapse of a year or several years; and this Römer did. But he found that there was apparently a manifest error in his predictions; he observed that there was some unaccountable irregularity in the eclipses and occultations; at one period of the year they appeared always to take place too late, and at another period too soon.

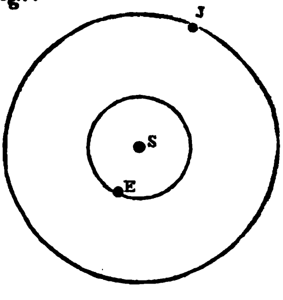
Fig.74



All this seeming irregularity was, however, explained in the most satisfactory manner by Römer, by the supposition that light is transmitted, not instantaneously, but with a certain finite, though very great velocity. The following was his explanation:—

Let E and J, fig. 74, represent the Earth and Jupiter revolving in their orbits about the Sun, S; and suppose it to be that period of the year when the Earth is between the Sun and Jupiter, as is shown in the figure. Now, in somewhat more than six months, the Earth and Jupiter will have come into the positions shown in fig. 75, the Sun being between Jupiter and the Earth; for the motion of Jupiter being much slower than that of the Earth, the former describes but a small portion of his orbit while the latter performs half the whole circuit, so that in a little more than half a year the two bodies will have come into the position represented by fig. 75.

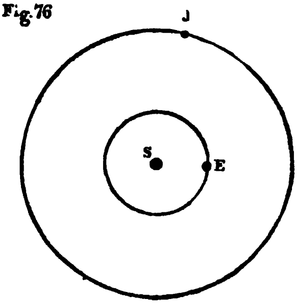
Fig.75



Now, Römer found that, in the position represented by fig. 74, the eclipses and occultations of the satellites appeared to take place eight minutes and thirteen seconds too soon, and in the position represented in fig. 75, they appeared to take place eight minutes and thirteen seconds too late. In fact, supposing the motions of the satellites to have been determined by observations made when Jupiter and the Earth were on the same side of the Sun, as in fig. 74, and the eclipses and occultations to have been predicted from the motions so determined, it was found, that in six months—i. e., when the Earth and Jupiter were on opposite sides of the Sun, as in fig. 75, the eclipses and occultations took place nearly sixteen minutes and a half later than the times predicted.

This was immediately explained, by supposing that the light, which conveyed to the eye, as it were, the intelligence of the eclipse or occultation having taken place at Jupiter, did not arrive instantaneously, but travelled with a certain velocity—namely, a velocity just sufficient to transmit it across the Earth's orbit in sixteen minutes and twenty-six seconds, or in round numbers, a velocity of twelve millions of miles per minute, the diameter of the Earth's orbit being about 190 millions of miles. For on this supposition it is clear, that since the Earth is farther from Jupiter in the position represented in fig. 75 than in fig. 74, by a distance equal to the diameter of the Earth's orbit, the eclipse or occultation would be seen sixteen minutes and twenty-six seconds later in the former position than in the latter, since the light would take that additional time to travel across the Earth's orbit when Jupiter and the Earth were on opposite sides of the Sun.

Fig. 76



273 That this is the real cause of the difference between the observed and predicted times of the eclipses and occultations, is in a great measure proved by making observations on the satellites during the whole year. It will be found that when the bodies are situated as in fig. 76, where S and E are at equal distances from J, the eclipses and occultations will occur eight minutes and thirteen seconds later than in the position fig. 74, the light then having to travel an additional distance equal to half the diameter of the Earth's orbit. And in the intermediate positions which the bodies occupy at different times of the year, it will be found that the number of minutes and seconds, which the eclipse or occultation appears to be later than in the position fig. 74, is always proportional to the additional distance the light has to travel over, in consequence of the Earth being farther from Jupiter than he is in the position fig. 74.

274 *Stellar Aberration.*—But the velocity of light shows itself in another curious phenomenon, called *stellar aberration*, which was discovered by the astronomer, Bradley. Respecting this subject we have only time to remark, that Bradley found out that the stars are observed to describe every year little orbits in the heavens; in fact, they always appear to be displaced from their true positions in the direction in which the Earth is moving. For instance, in spring the star γ Draconis when seen near the zenith, as it will be in the south of England, will appear to be nearly 20″ south of its real position, in summer nearly 20″ east, in autumn about the same distance north, and in winter about the same distance west of its true place; at which times the Earth is moving southward, eastward, northward, and westward, respectively. Stars 90° distant from the pole of the ecliptic, which it will be remembered is about half-way between Polaris and γ Draconis, appear to suffer no displacement when the Earth is moving either directly towards them or from them. In fact, this apparent displacement is found to diminish as the distance of the star from the point of the heavens towards which the Earth is moving diminishes.

275 Bradley showed that this phenomenon is completely and satisfactorily explained, by supposing it to arise from a combination of the Earth's motion and the motion of light. He was able to calculate what ought to be the velocity of light to give rise to this apparent displacement of the stars, and he found it to be the same as that determined by Römer from the eclipses and occultations of Jupiter's satellites. That the velocity determined by Bradley should agree with that given by Römer from such totally different observations and reasonings, is of course a most satisfactory proof of the truth of the hypothesis, *that light moves with a velocity of about twelve millions of miles per minute.*

We have dwelt longer on this optical fact than we shall do on others, on account of its great importance in astronomy.

276 *The Rectilineal Transmission of Light.*—That light is transmitted from luminous bodies in straight lines or rays, is so obviously true, that we need not say much on the subject. If we make a small hole in the shutter of a darkened room, so as to allow the sunlight to enter through it, the rectilineal course of the light will be made very evident by shaking out some dust from a puff-bag, which will be illuminated by the light. The fact that we cannot see round a corner, or through a bent tube, is a familiar proof that light travels in straight lines, and so also is the shadow cast by any opaque object, which is always exactly the shape traced out by straight lines drawn from the luminous point from which the light comes, through the different extreme points of the object.

277 Upon this property of light depends entirely its use as a means of ascertaining *direction*. We can tell in what direction an object is by looking towards it, but we cannot judge, by listening to sound, the direction of a sounding body, because sound does not proceed in straight lines or rays. We shall presently explain fully the means by which astronomers ascertain direction, by means of light.

II. *Inflection and Diffraction of Light.*

278 But though it be a fact, that in ordinary cases light proceeds in rays from luminous bodies, there are cases, often of practical importance, in which light spreads like sound. If the sunlight be allowed to enter a darkened room through a very small hole, (or, what is better, through a lens of short focus placed in front of a hole not quite so small,) the shadows cast by it will exhibit very curious appearances. They will be smaller than they would be if the light entered the room through a hole of moderate size, and of a totally different shape if the body casting the shadow be small; and their edges will be surrounded by coloured bands and bars, and, wherever there are sharp corners, by beautiful curved fringes.

279 To see these in great perfection, all that is necessary is a common spy-glass or telescope. Get a round piece of card the size of the object glass, and cut a hole in the middle, say the size of a shilling, over which gum a piece of sound tinfoil. Then, with a sharp pointed knife, cut carefully a small hole in the middle of the tinfoil of any shape, such as a triangle, a square, a cross, a star; or, with a needle, prick one, or two, or three, or a great number of holes in the tinfoil. Cover the object glass with this card, fastening it on with a little bee's wax, or otherwise. Then drop a little globule of mercury on a piece of black velvet, and lay it on a table or on the ground in the Sun's rays: in this manner a bright point of light will be produced. All that is to be done now is to look at this point of light through the telescope, holding it very steadily, or, what is better, fixing it on some stand, or supporting it on some books. When this is done, the most beautiful optical phenomena will be seen, which may be varied by drawing in or out the tube of the telescope, or by viewing the globule of mercury at a greater or less distance.

280 We have space here only barely to notice these phenomena, and to state that they arise from the fact that light spreads like sound when it enters a darkened room through a very small hole. The curious figures and colours are produced by what is called the *interference* of light, respecting which we cannot say anything here. These phenomena constitute what are called the *inflection* and *diffraction* of light.

281 We have thought it necessary to allude to these optical facts here, because they often prove a source of serious imperfection in astronomical and surveying instruments, and they often greatly add to the difficulty of making certain astronomical observations. We have seen levelling telescopes which could scarcely be used, on account of the wires in the focus being so affected by diffraction, as to appear like a number of indistinct bars; and we are convinced that opticians ought to be more familiar with this subject than they are. In microscopes of high power, with very small object glasses, the diffraction completely spoils the image formed by the instrument, especially when the object is illuminated by a small, well defined luminous surface.

III. *Reflection and Refraction of Light.*

282 We have stated that light is transmitted from luminous bodies in straight lines or rays, but this is true only when the light passes through vacuum, or through a perfectly uniform transparent medium,—i. e., either empty space, or space filled with some gaseous, liquid, or solid matter, which is all through of the same consistence and density. The air immediately surrounding the Earth's surface may be regarded as a uniform medium, but

at some distance upwards from the surface, the density of the air diminishes rapidly as we ascend. Near the Earth's surface, therefore, light passes through the air in straight lines, but this is not true except close to the surface.

283 *Refraction.*—Whenever the density or consistence of the medium through which light is passing changes, the direction in which the light moves is altered. In the case of light coming from a heavenly body to the eye, the path which the light pursues is continually bending as the light moves on, in consequence of the continual change of density of the atmosphere. When a ray of light enters a piece of glass, its direction is immediately changed, in consequence of the consistence of the glass being different from that of the air, out of which we suppose the light to pass into the glass. The same is true of water, oil, spirit, and of every transparent substance, in a greater or less degree.

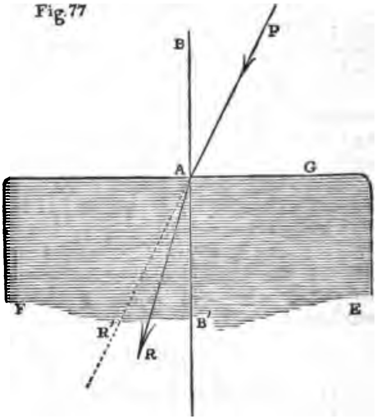
284 The change of direction which a ray of light experiences in passing from one medium into another, as, for instance, from air into glass, is called *refraction,* or the breaking or bending of the ray, as the word signifies. Refraction takes place generally whenever there is any change in the density, consistence, or nature of the transparent medium through which the light is passing.

285 The continual bending which a ray of light from a heavenly body experiences as it is passing through the atmosphere, is called *astronomical refraction.* This *error,* as it is called, affects a large and important class of astronomical observations, and it is therefore necessary to understand it, so as to be able to allow for it, and ascertain the true direction of the heavenly body from which the ray comes.

286 *Reflection.*—The refraction of light is always accompanied by what is called *reflection,* or a casting back of the light. When light is passing from one medium into another, a certain portion of it is always thrown back, or reflected, so that only part of the light enters the second medium. In the case of glass, when light enters it from the air, the portion of light which suffers reflection is small compared with that which enters the glass. In the case of a metallic medium, such as mercury or silver, a considerable portion of the light is reflected, and only a very small part enters the metal. Glass is therefore said to have a weak reflective power, but mercury or silver are said to be highly reflective.

287 *Laws of Reflection and Refraction.*—Let A E F, fig. 77, be any medium, a piece of glass for instance, and let P A be a ray of light which, passing out of air, or any other medium, enters the glass at A. Draw B A B′ at right angles to the surface of the glass at the point A. The ray P A is said to be *incident,*—i. e., to fall upon the glass at A, and therefore this ray is called the *incident ray.* The plane in which the ray P A and the perpendicular B A B′ lie, is called *the plane of incidence.*

Fig. 77



When the ray enters the glass, it is refracted, and proceeds in a different direction to that in which it was going before; let that direction be A R, A R′ being the former direction P A produced. The broken line P A R shows the whole course of the light, which proceeds in a straight line from P to A, is broken or refracted at A, and then goes on in a straight line to R.

Fig. 78

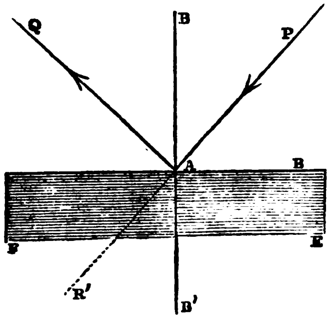


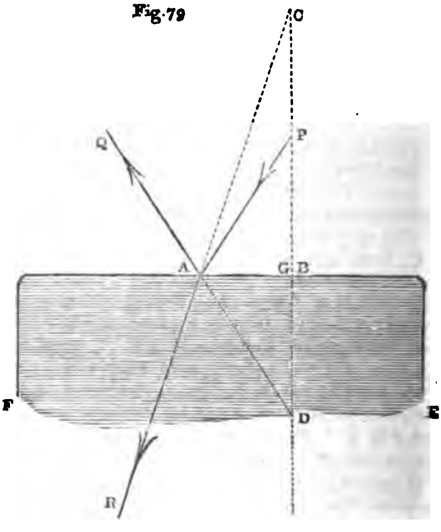
Fig. 78 shows a case of reflection. The incident ray P A, instead of going on in the straight direction A R′, is thrown back or reflected at A, and proceeds through the air in the direction A Q.

A R, fig. 77, is called the *refracted ray*, and A Q, fig. 78, the *reflected ray*.

288 The first law of reflection and refraction is this:—The reflected and refracted rays always lie in the plane of incidence; in other words, the three lines, P A, B A B′, and A R, fig. 77, and the three lines, P A, B A B′, and A Q, fig. 78, always lie in the same plane,—i. e., the incident ray, the perpendicular to the surface, the reflected ray, and the refracted ray, all lie in the same plane.

289 The second law may be stated in the following manner:—Let P A, A R, and A Q, fig. 79, be the three rays as before; A B, the surface of the medium, which we shall suppose to be a plate of glass; draw from any point B of the surface of the glass, a perpendicular, C P B D, meeting the incident ray at P, and the reflected and refracted rays produced backwards at D and C respectively; then the second law is, that A D is always equal to A P, and A C is always about one-half greater than A P,—i. e., three halves of A P.

Fig. 79



290 Whatever the medium may be, whether glass, or water, or oil, or any other substance, A D is always exactly equal to A P, and A C always exceeds (or falls short of) A P by a certain fraction of A P.

291 *Refractive Index.*—The proportion of A C to A P varies with the nature of the substance of which the medium A B E F is composed, and that of the medium out of which the light passes into A B E F. This proportion is called the *refractive index;* thus, if A C is always four-thirds of A P, which is very nearly the case when the medium A B E F is water, and the upper medium air, the refractive index is said to be $\frac{4}{3}$. A C may be always found by multiplying A P by a certain number or decimal, depending on the nature of the two media, and that number is called the refractive index.

292 The following table gives the refractive indices of different substances, supposing the light to enter each substance out of vacuum:—

Substance.	Refractive Index.	
Atmospheric air	1·000·294	about $\frac{10003}{10000}$
Water	1·336	about $\frac{4}{3}$
Alcohol	1·372	
Oil of olives	1·470	
Plate glass	from 1·500 to 1·550	about $\frac{3}{2}$
Flint glass	from 1·576 to 1·642	
Oil of cassia	1·641	
Sapphire.	from 1·768 to 1·794	
Diamond	from 2·439 to 2·755	about $\frac{5}{2}$

In this table it will seem that the refractive index is not always exactly the same for the same substance; as, for instance, in the case of sapphire, in some specimens it is as high as 1·794, and in others as low as 1·768. In the case of glass there is a considerable diversity of refractive index, on account of the different ingredients of which glass is made, and the different proportions in which they are mixed together.

293 The angle P A B which the incident ray P A makes with the perpendicular B A B′, figs. 77 and 78, is called the *angle of incidence*. The angle Q A B′ is, in like manner, called the *angle of reflection*, and R A B′, the *angle of refraction*.

Since A D is always equal to A P, it follows that both these lines are inclined at the same angle to the perpendicular C D; in other words, the reflected ray makes the same angle with the perpendicular to the surface that the incident ray does,—i. e., the angle of reflection is always equal to the angle of incidence.

294 Fig. 79 enables us to determine the course of the refracted ray by construction on paper, as follows:—

Having drawn a line A G, to represent the surface, and a perpendicular, B C, from any point of it; draw P A at the proper inclination to represent the incident ray. Measure A P, and open the compass to once and a half that distance, supposing the medium to be glass of the lowest refractive power; then, putting one point of the compass at A, describe a circular arc with the other, meeting B C at C, from which point draw the line C A R through A. This will give A R, the refracted ray.

295 The refractive index, when the light passes out of glass into air, is the reciprocal of that out of air into glass; that is, if the former be $\frac{3}{2}$, the latter is $\frac{2}{3}$. This is true of all substances; the refractive index, when light passes out of one medium (A) into another (B), is the reciprocal of that out of B into A.

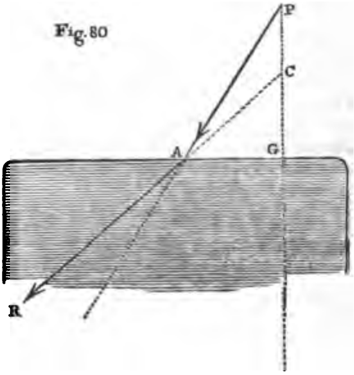


Fig. 80

296 The refractive index is always less than unity, that is, A C is always less than A P, when the light passes out of a denser into a rarer medium. Fig. 80 shows the course of the refracted ray in such a case. We may see, by comparing figs. 79 and 80, that when the light passes out of a rarer into a denser medium, the refraction, or bending of the ray, is *towards* the perpendicular, but out of a denser into a rarer it is *away from* the perpendicular.

297 If the refractive index, when light passes out of a medium A into a medium B, be multiplied by that out of B into another medium C, the result is the refractive index out of A into C. It

follows from this, that the refractive index out of A into C, divided by that out of A into B, gives the refractive index out of B into C. Thus, if the refractive index out of vacuum into glass be $\frac{3}{2}$, and that out of vacuum into water be $\frac{4}{3}$, that out of water into glass will be $\frac{3}{2}$ divided by $\frac{4}{3}$, that is, $\frac{9}{8}$.

IV. *Dispersion of Light.*

298 *Index of Refraction depends upon Colour.*—It is found by experiment that the refractive index depends, not only on the media out of and into which the light passes, but also on the colour of the light. The refractive index is greater when the colour is orange that when it is red; it is still greater when the light is yellow, still greater when green, greater again when blue, and greatest of all when violet.

299 *White Light Compound.*—It is also found that white light, such as the light of the Sun, or of a candle or lamp, is not simple but compound; each ray of white light being a union of several coloured rays, which are usually classed into seven kinds—namely, red, orange, yellow, green, blue, indigo, and violet. Each of these classes includes a variety of different shades; in fact, we may say that in reality a white ray of light is compounded of an infinite number of rays of different colour and shades of colour.

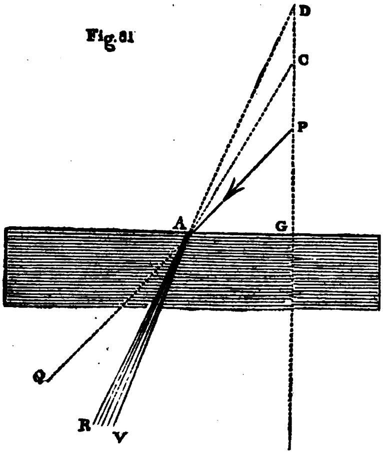
As we have stated, all these colours have different refractive indices. The following table for different substances will show the nature and amount of this diversity of refractive index.

Refractive Index for

Colour	Flint Glass.	Crown Glass.	Water.
Red	1·628	1·526	1·331
Orange	1·630	1·527	1·332
Yellow	1·635	1·530	1·334
Green.	1·642	1·533	1·336
Blue	1·648	1·536	1·338
Indigo	1·660	1·542	1·341
Violet	1·671	1·547	1·344

300 *Dispersion of White Light by Refraction.*—Let P A be a ray of white light incident at A, on the surface of any medium, say crown glass; then, in order to find the course of the light after it has entered the glass, we must proceed to make the construction already explained, remembering that the different colours which compose P A have all different refractive indices, as shown in the table we have just given. Thus for red the index is 1·526; therefore if we suppose A P to be 1, and make A C equal to 1·526, A R, which is A C produced, will show the course of the red ray after refraction. In like manner, since 1·547 is the index for violet, if we make A D equal to 1·547, A V, which is A D produced, will show the course of the violet ray after refraction. In the same way we may find the intermediate refracted rays, the orange, yellow, green, &c.

Fig. 81

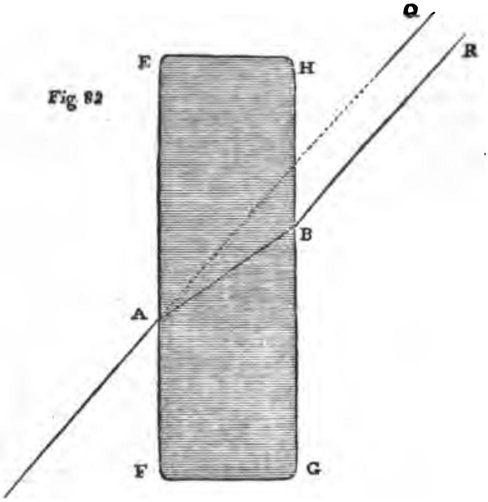


Hence it is manifest that the various coloured rays which were united in the white ray P A, will, after refraction at A, be separated, and pass through the piece of glass in different directions; the red ray A R being least bent out of its original direction P A Q, the violet most, and the intermediate colours in order in an intermediate degree. The white ray P A is therefore, as it were, *dispersed* as soon as it enters the glass into a set of coloured rays diverging from the point A. In this manner the dispersion of white light is produced by refraction.

V. *Passage of Light through Plates, Prisms, and Lenses.*

301 *Passage of Light through a Plate of Glass or other transparent Substance.*—By a plate of glass we mean a piece bounded by plane surfaces which are parallel to each other. Let E F G H, fig. 82, represent a section of such a piece of glass at right angles to the parallel plane surfaces represented by E F and G H. Suppose that a ray of light P A falls upon the surface E F at the point A; then the course of this ray in passing through the glass will be as follows:

Fig. 82



The ray will of course be refracted at A, and instead of going on in the direction A Q, which is P A produced, it will pass through the glass in the direction A B, which, as we have stated, is less inclined to the perpendicular to the refracting surface than A Q is. At B the ray will pass out of the glass into the air, and therefore again suffer refraction; but since it passes from a denser into a rarer medium, it will be bent away from, not towards, the perpendicular. In fact, the refraction or degree of bending at B, will be precisely of the same amount as at A, only it will take place in the opposite direction; this may be easily proved by making the proper construction for the refraction at A and B, according to the method we have explained above, remembering that the index of refraction at B is the reverse or reciprocal of that at A.

The consequence of this will be, that the ray will emerge from the glass at B in a direction B R, parallel to the original direction P A Q; for whatever be the angle through which the ray is bent at A, it will be bent through the same angle in the opposite direction at B, and therefore be restored to its original direction.

302 Hence, when a ray of light passes through a plate of glass, it will emerge parallel to its original direction, but it will suffer a certain degree of lateral displacement—i.e., BR will be parallel to, but not coincident with, PAQ.

303 *Passage of Light through a Prism.*—By a prism we mean a piece of glass or other transparent substance, bounded by plane surfaces which are not parallel, but inclined to each other at a certain angle. Let E F G, fig. 83, represent a section of such a piece, at right angles to the two plane surfaces which are shown by the lines E F and E G. Suppose that a ray of

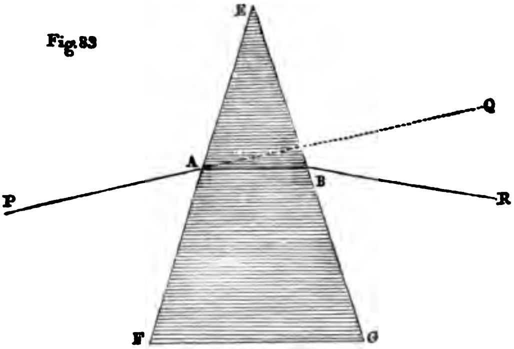


Fig. 83

light P A falls upon the surface E F; then the course of this ray in passing through the glass will be as follows:

The ray, being refracted at A, will be turned towards the perpendicular to the surface E F, and pass through the glass in the direction A B. At B it will suffer a second refraction, and will be turned away from the perpendicular to the surface E G. The effect of the second refraction will be, not to turn the ray back to its original direction, but to make it deviate still farther away from it, as is evident from the figure. Thus the ray, instead of going on in the direction A Q, which is P A produced, will emerge out of the glass in the direction B R.

The effect of the prism here is to turn the ray, not towards the angle E, but towards the thicker part of the prism F G; and this is always the case, supposing the prism to be made of glass, or any transparent substance denser than the air; the ray will always be bent away from the angle of the prism towards the thicker part.

304 *Dispersion produced by a Prism.*—The two refractions which take place when a ray of light passes through a prism have the effect of producing a considerable degree of dispersion, and showing the composition of white light, and the different refrangibility of the coloured rays composing it, in a very striking manner. All that is necessary to exhibit the dispersion of light in great perfection by a prism is, to allow a ray from the sun to enter a dark room through a hole or slit in a shutter, and then to intercept it by a prism, and receive the transmitted light on a screen, or on the wall or ceiling. Let E F G, fig. 86, represent the prism, P A, the ray from the Sun falling on the surface at A. Suppose the red ray to pass through the prism in the direction A B, and to emerge into the air again in the direction B R; then the violet ray will be more refracted at A than the red, and therefore pass through the prism in a direction A C, more inclined to A Q (A Q being P A produced) than A B is. Again, the violet ray will be more refracted at C than the red

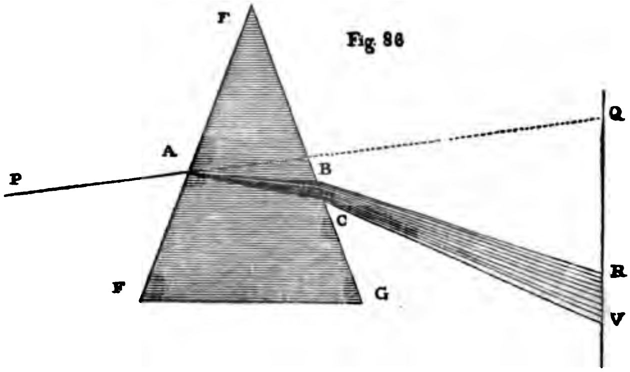


Fig. 86

is at B, and therefore it will emerge in a direction C V, more inclined to A Q than B R is.

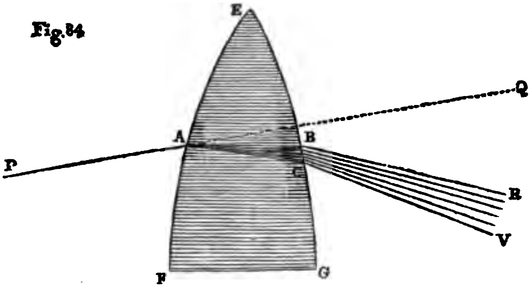
Hence, if the emergent light be received on a screen Q R V, at some little distance from the prism, a red spot will be seen at R, and a violet spot at V. In the space intermediate between R and V will be seen the intermediate colours. The order of the colours will be as follows:—

Red at R.
Orange.
Yellow.
Green.
Blue.
Indigo.
Violet at V.

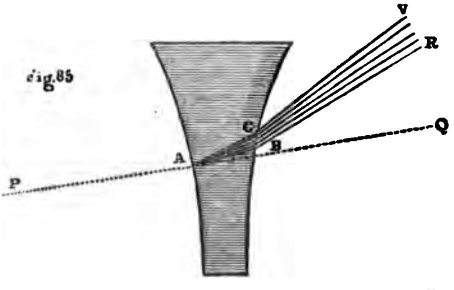
The coloured space between R and V is commonly called the *Prismatic Spectrum.*

305 If the sides E F E G of the prism be curved instead of plane, the effect it produces on light passing through it will be the same—see figs. 84 and 85, which represent prisms with curved sides, and where the course of the light is represented by the same letters as in fig. 86.

Fig. 84



It is important to observe the double difference of the effect produced by the two prisms represented in figs. 84 and 85.



1st. The emergent rays B R C V are *below* A Q (the original direction of the light) in fig. 84, and *above* A Q in fig. 85. In other words, the light in both cases is bent *towards* the thicker side of the prism.

2ndly. The violet is below the red in fig. 84, and above ~~it in~~ fig. 85. In other words, the violet is in both cases on the thicker side of the ~~prism, and~~ the red on the thinner side.

306 *The Compound Achromatic Prism.*—A prism which produces refraction without dispersion—i. e., one which bends all the coloured rays equally, is said to be *achromatic*—i. e., without colour. A single prism, such as one of those we have just spoken of, cannot be achromatic, as is evident from what we have explained. But by putting two prisms together, as in fig. 87, it is possible to make a compound prism which shall be achromatic or nearly so. We shall briefly explain how this is done. The two prisms, E F G and E′ F′ G′, are placed in opposite positions, and therefore produce opposite

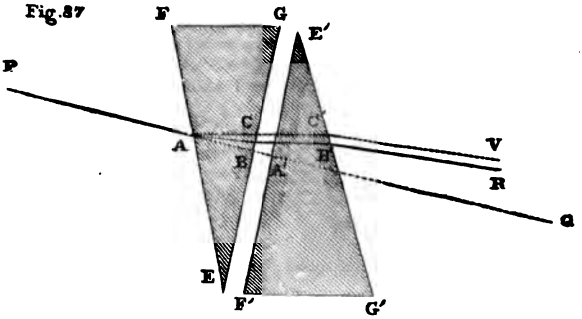


Fig. 37

refractions and dispersions; the prism E F G will bend the rays upwards, and throw the violet above the red; while the other prism E′ F′ G′ will have the reverse effect. P A B A′ B′ R represents the course of the red ray through the two prisms, the dotted line A C C′ V, the course of the violet, and A Q is P A produced.

Now, suppose that the refraction produced by the first prism amounts to 10°, and the dispersion to 1°. By saying that the refraction is 10°, we mean that the prism turns the red ray 10° out of its original direction A Q, and by saying that the dispersion is 1°, we mean that the violet ray is turned 1° more than the red out of its original direction—i. e., that the violet ray is turned 11° out of its original direction. Secondly, suppose that the refraction produced by the second prism is 8°, and the dispersion 1°. The effect of the two prisms may be calculated as follows :—

Refraction produced by first prism	10° upwards.
„ „ by second	8° downwards.
Total refraction produced by both prisms . .	2° upwards.
Dispersion produced by first prism	1° upwards.
„ „ by second.	1° downwards.
Total dispersion produced by both prisms. .	0°

Hence these two prisms will produce a total refraction of 2° without dispersion, and so form a compound achromatic prism.

307 Whether it is possible to make prisms which will produce such effects as we have here supposed, is a point to be decided by experiment. Newton concluded from some imperfect experiments that it was not possible to do so; that if the dispersions produced by the two prisms were equal and opposite, as we have supposed, the refractions would also be equal and opposite—that is, that if the total dispersion were nothing, so also would the total refraction; in other words, he concluded that it was a physical impossibility to obtain refraction without dispersion. From this erroneous conclusion, he gave up all hope of making achromatic telescopes, and turned his attention to reflecting telescopes.

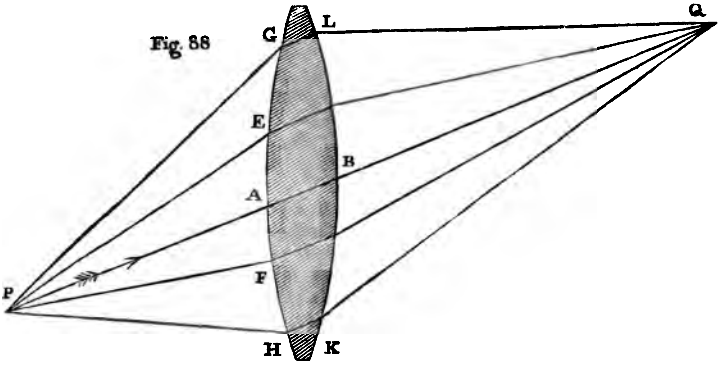
308 Mr. Hall, a Worcestershire gentleman, and after him the celebrated optician Dollond, found that Newton's experiments were inaccurate, and proved that, by making one of the prisms of flint glass, and the other of crown glass, a compound achromatic prism might be formed, which would produce a certain amount of refraction without dispersion.

309 *Secondary Spectrum.*—It is possible in this way to destroy the dispersion, as far as the red and violet rays are concerned; but this will not, at the same time, answer for the other colours, as, for instance, the red and green. If, on the other hand, the dispersion is destroyed as far as regards red and green, it will not be quite destroyed as far as regards red and blue. A com-

pound prism, such as the above, cannot be made perfectly achromatic for all the colours; but by putting three or more prisms together this may be done, at least to a sufficient degree of accuracy. The light which passes through the compound prism, fig. 87, will therefore exhibit some traces of colour if received on a screen. The slightly coloured spot it makes on the screen is called the *Secondary Spectrum.*

310 *Passage of Light through Lenses.*—A lens (from *lens*, a bean) is a circular piece of glass, bounded by two curved surfaces. Generally these surfaces are spherical, and not very much curved, except in a lens of very high power. When the surfaces are convex or curved outwards, the lens is said to be convex; when inwards, concave. The best way to distinguish between the two kinds of lenses is to say that a convex lens is *thicker* in the middle than at the extreme parts, and a concave thinner.

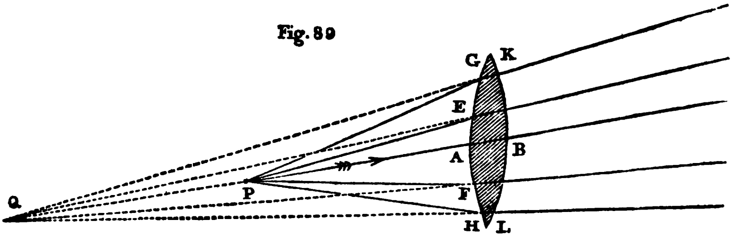
Fig. 88



311 *Convex Lens.*—Fig. 88 represents the passage of rays through a convex lens. G H K L represents a section of the lens by a perpendicular plane through the middle, G A H showing one of the bounding surfaces, and L B K the other. A number of rays P G, P E, P A, P F, P H, are supposed to diverge from a point P, and fall on the surface G A H of the lens. The ray P A, which is supposed to pass through the central part of the lens, will not suffer any deviation, but pass straight through the lens in the direction A B Q, which is P A produced. The reason of this is, that the surfaces of the lens at A and B are parallel to each other, and therefore the ray passing through the lens in the direction A B, will be transmitted in the same manner as if the lens were a plate of glass with parallel planes. Now, we have shown in such a case, that the light on coming out of the glass will resume its original direction, and suffer only a slight degree of lateral displacement (*see* fig. 82). The lens is generally so thin, that we may neglect taking any account of this lateral displacement, and therefore we have drawn the ray P A B Q straight through the lens in one unbroken line.

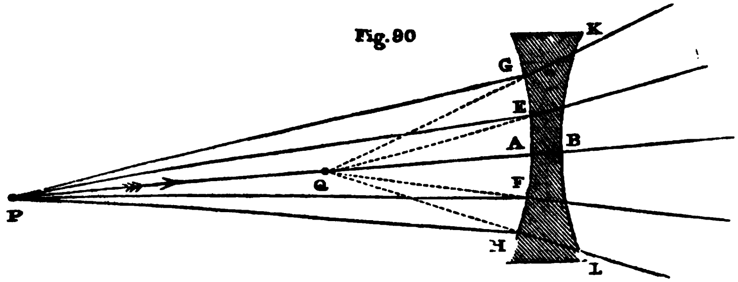
As we have explained in the case of the prism, the other rays, P G, P E, P F, P H, will be bent towards the thicker part of the lens, and therefore they will emerge from the lens as shown in fig. 88, or as in fig. 89.

Fig. 89



312 In one case, fig. 88, the lens is supposed to be sufficiently powerful to bend the rays so as to make them converge towards, or nearly towards, some point Q, on the line P A produced. In the other case, the lens not being so powerful, the rays are not bent sufficiently to converge to a point in front of the lens, they are only made less divergent than they were before passing through the lens. In fact, if we produce them backwards they will meet, or nearly meet, in a point Q, behind P on the line P A produced backwards.

Fig. 90



313 *Concave Lens.*—Fig. 90 represents a concave lens and the passage of the light through it, the letters denoting the same things as before. The ray P A which passes through the central part of the lens will go on straight without deviation; the other rays, P E, P F, P G, P H, will be bent towards the extreme parts K and L of the lens, which are now thicker than the central part A B. The effect of this will be to increase the divergence of the rays, so that, on producing them backwards, they will meet, or nearly meet, at a point Q, in front of P on the line P A.

314 We have in all these cases represented the ray P A as passing somewhat obliquely through the lens; of course all that has been said will apply equally when P A passes perpendicularly instead of obliquely.

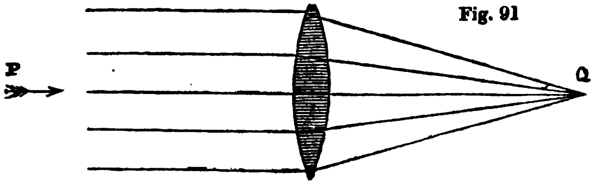
315 *Focus.*—A point in which rays of light meet is called a *focus*, a name derived from the Latin word signifying 'fire-place,' because objects placed in the focus of a burning lens were set fire to. The point P is called the *focus of incident rays*, and the point Q the *focus of emergent rays*.

In fig. 88, the emergent rays actually cross at Q; but in figs. 89 and 90, this is not the case, the emergent rays proceed, however, just as if they diverged from the point Q, and we may regard Q as an imaginary focus. Q, in fig. 88, is called a *real focus*, and in figs. 89 and 90, a *virtual* or *imaginary focus*.

316 *Principal Focus. Focal Length.*—When the incident rays come from the Sun, or any other very distant body, the focus of emergent rays is called the *principal focus* of the lens, and the distance of this focus from the lens is called the *focal length* of the lens. When the point P is very distant, the rays P G, P E, P A, P F, P H, will be inclined to each other at extremely small angles, so small, that we may consider the rays to be parallel to each other. We may therefore define the principal focus to be the focus of emergent rays when the incident rays are parallel.

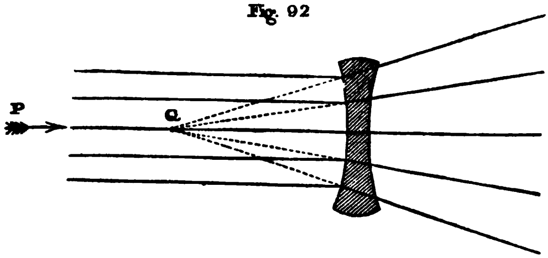
317 If parallel rays fall on a convex lens, as in fig. 91, where the focus P

Fig. 91



of incident rays is supposed to be at a great distance from the lens, it is evident, from what has been said, that the emergent rays will converge towards a point Q in front of the lens. Hence the principal focus of a convex lens is *in front* of it, and is a *real* focus.

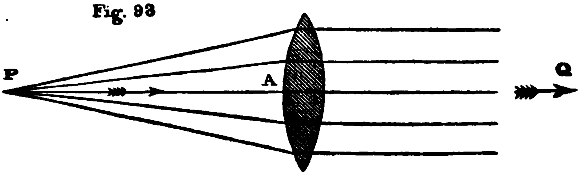
Fig. 92



318 If parallel rays fall on a concave lens, as in fig. 92, the emergent rays will diverge, and therefore the principal focus is *virtual*, and *behind* the lens.

319 If the distance P A be equal to the focal length of the convex lens, the rays will emerge parallel to each other, as is shown in fig. 93, where Q is supposed to be at an infinite distance from the lens. That this will be the case is evident, by supposing the course of the light in fig. 91 to be reversed —i. e., to come from Q instead of P.

Fig. 93



320 If P A be less than the focal length, the rays will emerge diverging, and if P A be greater than the focal length, the rays will emerge converging.

321 Hence we may make the following comparative statement respecting convex and concave lenses.

A convex lens either diminishes the divergence of rays or makes them convergent. We may say that the effect of a convex lens is *always* to produce a certain degree of convergence, for we may consider that diminishing the divergence of the rays is nothing more than producing a certain amount of convergence, which partly destroys the divergence of the rays, and therefore has the effect of making them less divergent than before.

A concave lens always increases the divergence of rays.

A convex lens sometimes brings the emergent rays to a focus *in front* of the lens, but a concave lens never does so.

A convex lens may be used to make diverging rays parallel; a concave to make converging rays parallel. In both cases, the distance from the lens of the point from which the rays diverge, or to which they converge, must be equal to the focal length of the lens.

322 *Achromatic Lens.*—A single lens, such as one of those we have just described, produces its effect by refracting the rays just like a prism, and so bending them towards or from the central ray, according as the lens is convex or concave; but this refraction will be accompanied by dispersion; the violet rays will always be more refracted than the red rays, and therefore, in the case of a convex lens, the violet rays will emerge more inwards—i. e., more towards the central ray, than the red rays do; but in the case of a concave lens, the violet ray will emerge more outwards than the red.

If, however, we put two lenses together, one convex and the other concave, such that the outward dispersion produced by one may be just equal to the inward dispersion produced by the other, the total amount of dispersion produced by the two lenses in combination will be nothing, as in the case of the two prisms above explained. At the same time, by making one lens of crown glass, and the other of flint glass, there will be a certain amount of refraction still produced. In this manner the lenses will bend the rays sufficiently for practical purposes without dispersing them, at least, without any serious amount of dispersion, for there will always be some arising from the secondary spectrum.

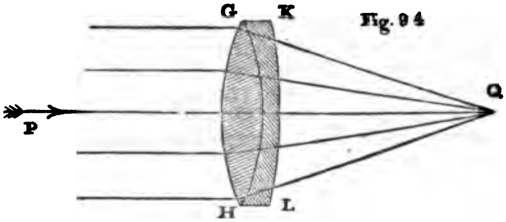


Fig. 94

323 It is usual to put the lenses together as in fig. 94, G H being the convex, and K L the concave lens, the former being made of crown glass, and the latter of flint glass. In the telescope, the convex lens is always that on which the light first falls, and in the microscope the reverse is the case. The manufacture of achromatic lenses is now brought to great perfection. The difficulties of grinding, polishing, and fitting them properly together are considerable, especially when the combination is required to be powerful—i. e., of short focal length.

324 *Spherical Aberration of Lenses.*—We have hitherto, in the figures we have given, represented the emergent rays as meeting in one point Q; but this is only true approximately; the extreme rays P G and P H, after passing through the lens, will meet the central ray P A B at a point Q′, (see fig. 95,) at some little distance from the point Q, where the intermediate rays P E P F, after emerging from the lens, meet the central ray P A B. In other words, the focus of the extreme emergent rays will be a different point from the focus of the intermediate emergent rays. If we suppose the rays P E and P F to be near the central ray, Q is considered to be the true focus, and Q′ is regarded as an erroneous focus. The error in the position of the focus Q′, which ought to coincide with Q, is called *spherical aberration,* because it arises from the spherical form of the two surfaces of the lens. It is impossible mechanically to grind the surfaces of lenses in any but spherical forms; but such forms are not those which cause the extreme and intermediate rays to be refracted to the same point; this error or aberration is therefore caused by the spherical forms of the lenses.

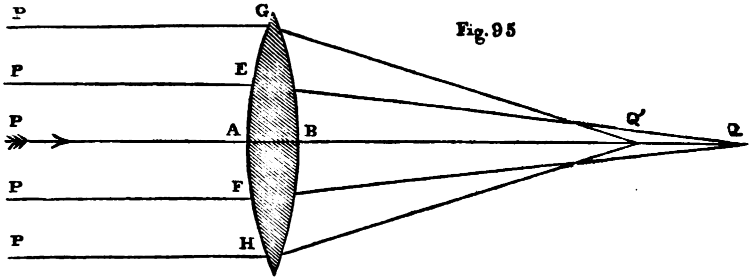


Fig. 95

325 In most cases a convex lens produces a backward aberration of the focus, that is, the point Q′ is behind the point Q, as in fig. 95; but a concave lens generally produces a forward aberration, that is, Q′ is in front of Q. In other words, one lens refracts the extreme rays too much, the other too little.

Now, by putting the two lenses together, as in fig. 94, one convex, the other concave, and by giving a proper spherical shape to their surfaces, we make the two opposite aberrations produced by the lenses almost entirely neutralise each other, and so cause all the emergent rays to converge very nearly to the same point. When the two lenses are properly made, the over refraction of the extreme rays by the first lens will be counterbalanced by their under refraction by the second lens. In this manner a compound lens may be constructed free from any serious amount of spherical aberration. Such a lens is said to be *aplanatic*, from the Greek, signifying 'free from error.'

Lenses which form the object glass of good telescopes and microscopes, are always made both achromatic and aplanatic.

Having now explained briefly those optical principles which are absolutely necessary to be known by persons who wish to understand astronomy practically, and to use astronomical instruments, we shall go on in the next chapter to consider the formation of optical images, by rays passing through a hole or a lens falling on a screen; from which simple, though really instructive case, we shall derive the construction of the telescope and microscope, and explain their uses.

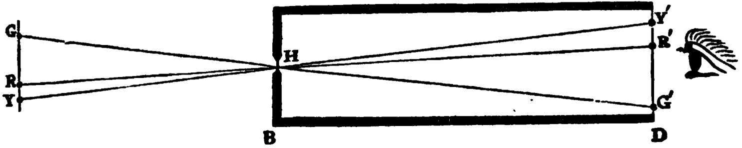
CHAPTER VI.

FORMATION OF IMAGES—VISION—THE TELESCOPE, MICROSCOPE, AND MICROMETER—THE VERNIER.

I. *Formation of Images by a Hole or a Lens.*

FORMATION of Images on a Screen by means of a Hole.—Let A B C D, fig. 96, represent a box or tube, in one end of which A B is a very small hole H, and at the other end a semi-transparent screen C D, made of ground glass, or thin silver paper, or a piece of smooth glass with a film of milk dried upon it. The eye is supposed to look at this screen, and an object G Y is placed before the hole H: then the following effect will be produced:—

Fig. 96



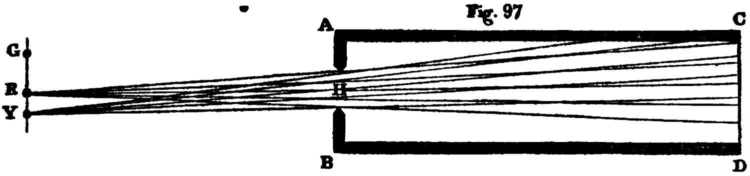
Supposing for an instant that the object G Y consists simply of three luminous points, one green, another red, and the third yellow, which are represented by G R and Y, respectively. Then green rays will issue in all directions from G, some of which, proceeding in the direction G H, will pass through the hole H, and, going straight on, will fall on the screen C D at G′, the points G H and G′ being in the same straight line. The eye will therefore see a small green spot on the screen at G′. In like manner some of the red rays from R, passing through the hole and going straight on to R′, the points R H and R′ being in the same straight line, will form a small red spot at R′, which the eye will see. In like manner, also, a small yellow spot will be seen at Y′, the points Y H and Y′ being in the same straight line.

Hence the eye will see three small spots on the screen, exactly similar to. and at the same relative distances from each other as the points G R and Y of the object, only inverted in position; in fact, an inverted image or likeness of the object will thus be cast on the screen C D.

Precisely the same reasoning would apply to an object consisting of any number of luminous points, and therefore it follows, that whatever object is placed in front of the hole H, a perfectly accurate inverted image of it will be formed on the screen C D.

327 *Defect of the Image thus formed.*—The hole H must necessarily be a very small hole, otherwise a distinct image will not be formed on the screen. This will be evident immediately, from fig. 97, in which H is supposed to be large. It will be seen in this figure that the red and yellow rays, after passing through the hole, get mixed together, and fall nearly on the same part of the screen. The consequence of this will be, that instead of two distinct small spots, one red and the other yellow, being seen on the screen, as in fig. 96, there will be but one large spot seen, consisting of a confusion of red and yellow. Hence it is manifest that, by enlarging the hole H, we make the image on the screen indistinct and confused. Indeed, however small the hole may be, there will always be a certain degree of indistinctness, arising from the mixture and confusion of rays coming from points of the object very near each other. In fact, a little consideration will show that the rays from two points of the object, not farther from each other than a distance equal to the diameter of the hole, will always be mixed together before they reach the screen.

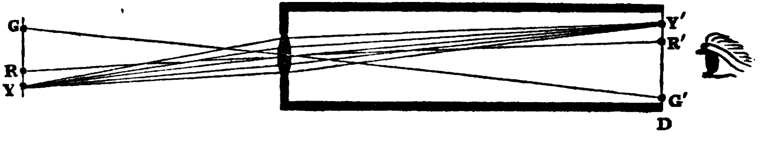
Fig. 97



Now, this is a serious defect; for, when the hole is extremely small, the light that falls on the screen becomes too faint, and can scarcely be seen. Hence there is an inevitable fault in this instrument; the image on the screen is either too faint or too indistinct, and we cannot diminish one imperfection without increasing the other.

328 *Use of a Lens placed in the Hole.*—Let us now suppose that we enlarge the hole, and put a lens in it, as is represented in fig. 98, of sufficient power to produce convergence in rays diverging from any point Y of the object, and bring them to a focus at Y′ on the screen. As we have already explained, the point Y′ will be found by drawing a line through the centre of the lens from Y, to meet the screen in Y′. In like manner, if we draw a line from any other point R of the object, through the centre of the lens, to meet the screen in R′, the rays diverging from R will be brought to a focus at R′; and the same may be said of G, and of every other point of the object.

Fig. 98



Hence it is evident that an image will be formed on the screen of exactly the same size and shape, and as distinct and free from confusion as the image in fig. 96, supposing the hole in that figure to be extremely small. But there will be this important difference between the two images: the quantity of light admitted through the lens will be very much greater than that admitted through the hole in fig. 96, and therefore, while the image in fig. 98 is perfectly distinct, it will at the same time be bright and clear.

The use of a lens is, therefore, most important; with a good aplanatic and achromatic lens, a very perfect image may be formed on the screen, as we know by the beautiful photographic pictures which are produced by an instrument of the kind represented in fig. 98.

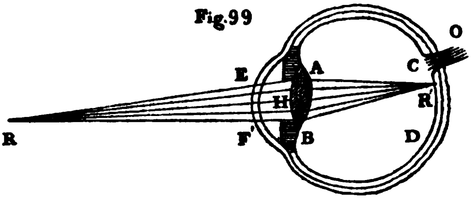
329 This instrument is called a *camera obscura*, or "dark chamber;" we introduce it here with a view to the better explanation of the telescope, and its various uses in astronomy.

330 It is important to observe that the different points of the image are found by drawing straight lines from the corresponding points of the object, through the centre of the lens, to meet the screen; and from this it follows that the image, though inverted, must be accurately similar to the object.

II. *Of Vision.*

331 *The Eye is a sort of Camera Obscura.*—A section of the eye is represented in fig. 99. It is a round ball consisting of certain transparent fluids enclosed in an opaque membrane. In front there is a hole H, called the *pupil*, before which is a transparent fluid, called the *aqueous humour*, enclosed in a delicate membrane, the whole being kept in and protected by a strong horny and transparent substance, E F, called the *cornea*. Behind the hole H is a very clear lens A B, called the *crystalline lens*, between which and the back of the eye is another humour, called the *vitreous humour*. Lastly, C D is a nervous membrane, called the *retina*, spread out to form a screen at the back of the eye: it consists of a network of fine nerves, which, uniting at a point called the *punctum cæcum*, form the *optic nerve* O, by which luminous impressions made on the retina are conveyed to the brain. The interior surface of the eye is darkened, probably to prevent stray light, by a black substance, called the *pigmentum nigrum*.

Fig. 99



332 It will be easily seen from this description that the eye is a sort of camera obscura. The pupil H corresponds to the hole in front of the tube in figs. 96, 97, 98; the retina corresponds to the screen C D; and the crystalline lens, assisted by the cornea, which is a sort of lens, serves, like the lens in fig. 98, to bring the rays to a focus on the retina or screen. The humours in the interior of the eye serve to keep it in its proper globular shape, though they are also intended to assist in the optical performance of the eye to a certain extent.

In fig. 99 the course of rays falling on the eye from a luminous point R is shown; a certain portion of these rays are admitted through the pupil or hole H, and are then caused to converge to a point R′ of the retina or screen. In this way every point of an object placed before the eye has a corresponding image on the retina, and therefore an image of the whole object will be formed on the retina, clearly inverted, as in the case of the camera obscura. The optic nerve conveys this image to the brain in some mysterious way, and an idea of the external object is thus produced in the mind.

333 It is, of course, necessary that the image* formed on the retina should be perfectly distinct and free from confusion, otherwise no clear idea of the external object could be conveyed to the mind. The lenses in front of the eye—namely, the cornea and crystalline lens, must therefore be just of suffi-

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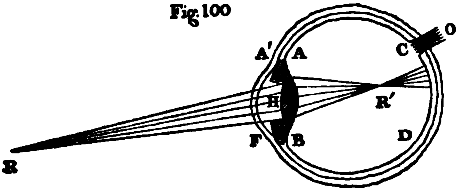
* It is enough that a very small portion of the image should be distinct, (namely, that portion formed at the point of the retina called the foramen centrale.) This appears from the fact that we can see only one point of an object distinctly at a time.

cient power to bring the rays to a focus on the retina. This is represented in fig. 99.

334 In fig. 100 is represented the case when the lenses of the eye are too strong, so that they cause the rays to converge too rapidly, and so bring them to a point R′, in front of the retina. The consequence of this will be, that instead of a point on the retina, we shall have a spot of light of some size, and this will destroy the distinctness of the image; for the different spots which correspond to neighbouring points of the object, will overlap each other, and so be mixed and confused with each other, exactly in the manner we have already explained in speaking of the effect of enlarging the hole in the camera obscura, Art. 327.

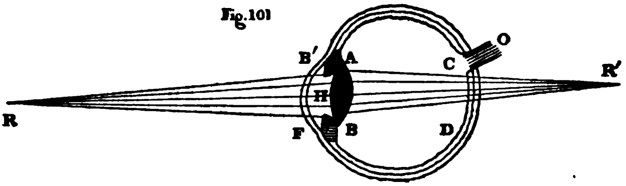
Fig. 100



335 When, however, the point R is much nearer to the eye than is represented in the figure, the rays which fall on the eye from it will be very divergent, and it will require more powerful lenses to make them converge; therefore, though the lenses were too powerful before, they may not be so now; in fact, they may be only just sufficiently strong to overcome the increased divergency of the rays, and make them converge to a point on the retina exactly. Hence it appears that, when the lenses of the eye are too powerful, an object which cannot be seen distinctly at some distance, will become distinctly visible when it is brought sufficiently near the eye.

This is the case with short-sighted persons, and therefore such persons have too powerful eyes, which is generally evident by the more than usual roundness of the cornea.

Fig. 101



336 In fig. 101 is represented the case where the lenses of the eye are too weak, so that they do not cause the rays to converge with sufficient rapidity, the consequence of which is, that the rays are intercepted by the retina before they come to a focus. This will of course produce indistinctness of vision, just as in the former case.

When the lenses are too weak, the object may be made more distinctly visible by removing it to a greater distance from the eye, and so diminishing the divergence of the rays, which will allow the weak lenses to produce a greater degree of convergence, and so bring the point R′, towards which the rays converge, nearer to the retina. Persons with weak lenses are therefore long-sighted.

337 Most eyes are adapted for vision of distant objects, the lenses being only just powerful enough to bring rays from a distant point to a focus on the retina. But the lenses may be made more powerful by the action of certain muscles, which, by compressing the ball of the eye, and so making the cornea rounder, increase the power of the cornea, and possibly that of the crystalline lens also. By the almost involuntary action of these muscles, the eye has a power of adapting itself to near objects; but generally this power of adaptation is limited to objects not nearer to the eye than six inches, or thereabouts. The eye is perfectly incapable of seeing nearer objects without the assistance of a microscope.

338 It is easy to understand, from what has been stated, how the vision of short-sighted persons is assisted by their looking through a concave lens, for that lens increases the divergence of the rays, and has the same effect as if the object were brought nearer to the eye.

339 In like manner, it is evident how long-sighted persons are benefited by convex lenses, which diminish the divergence of the rays, and therefore have the same effect as removing the object to a greater distance from the eye.

340 It is important to observe here, that it follows from what we have explained respecting the eye, that a near object and a distant object can never be seen distinctly at the same time; for it is plain that if the lenses are of the proper power to bring the more diverging rays, which come from a nearer object, to a focus on the retina, they will not be of the proper power to produce the same effect on the less diverging rays which come from more distant objects. This is a point of some importance in practice.

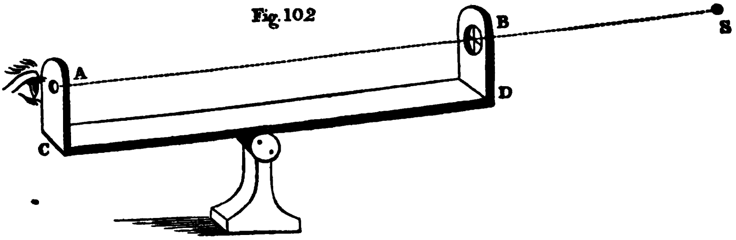
We have now said enough respecting light generally, and the formation of images, to enable us to proceed to the two special subjects we have to consider in the present chapter—namely, the telescope as a means of ascertaining *direction*, and the microscope as a means of measuring *minute distances*.

III. *Of the Telescope as a means of ascertaining Direction.*

341 *Direction how determined by Sights.*—Simple as it may seem at first sight, it is no easy matter to determine and define the direction in which any distant object appears to be. In a rough way, we might point a straight rod at the object, and say that that rod showed the direction of the object; but it is not possible to point a rod in this way with any degree of accuracy.

By putting a pair of sights on the rod, the direction of the object may be much more accurately ascertained. Fig. 102 represents a rod C D, with two sights A and B fixed upon it, A being a small hole, and B a larger hole, with two cross wires. By looking in such a manner through the hole A, and putting the rod in such a position that the point of intersection of the wires appears to coincide with a distant object S, and at the same time with the centre of the hole, it is evident that we ascertain the direction in which S is seen, for the line joining the centre of the hole and the point of intersection of the cross wires shows that direction.

Fig. 102



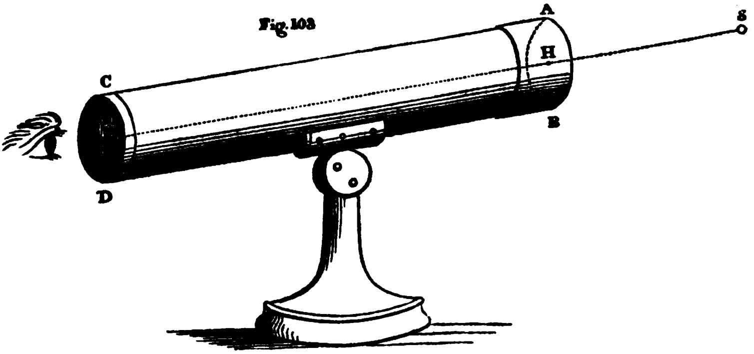
342 This method of ascertaining direction is, however, by no means sufficiently accurate, for several reasons, and among the rest for this—that the eye cannot possibly see the hole at A, the cross wires at B, and the object S, all distinctly at the same time. If the attention be fixed on S, it will be seen distinctly, but the cross wires will not, and the hole will appear quite indistinct. In practice, the hole at A is often very small, and the eye is put quite close to it, in which case the hole is scarcely seen, and only serves to show the place where the eye should be put.

We shall now show that the camera obscura, above described, affords a most simple and accurate method of determining direction, especially with certain additions, which convert it into a telescope.

343 *Direction how determined by a Camera Obscura.*—We shall suppose

the camera obscura to consist of a tube, A B C D, fig. 103, C D being the semi-transparent screen on which the image is formed. At the other end A B, is the lens, which is of the proper power to make the rays which come from a distant luminous point S, converge to a focus on the screen C D; but, as we have shown above, this lens produces precisely the same effect on the screen as an extremely small hole H, only the image formed by the lens is not extremely faint, like that formed by the hole.

Fig. 103



As we are only concerned with the size and shape of the image, and not with its brightness, we shall for simplicity suppose that there is a hole H, instead of a lens, at A B, the hole representing, in fact, the centre of the lens. On the screen C D there are two fine wires or lines, intersecting each other at right angles; the use of these lines is to make, by their intersection, a fixed mark at a particular point of the screen.

344 The imaginary line drawn from the point of intersection of the two cross wires through the point H, is called the *line of collimation* of the instrument, that is, as we have explained before, the line which is pointed or aimed at any distant object, and which is the direction in which that object is seen.

345 Now, we can evidently ascertain, with the greatest precision, whether the line of collimation points to any distant point S, or not; for we have only to look at the image S′ of the point S, found on the semi-transparent screen, and see whether it coincides with the intersection of the cross wires or not. If it does, then the line of collimation must point exactly to the point S, for, as we have explained above, S′ H and S are always in the same straight line, and therefore, if S′ is seen at the point of intersection of the cross wires, it follows that the point of intersection of the cross wires, the point H, and the point S, are in the same right line; or, in other words, the line of collimation points to S.

346 If S′ were a material point, instead of being a mere optical image, as it is, it would not be possible to see whether S′ coincided exactly with the intersection of the cross wires or not; for, in point of fact, it is impossible to see with accuracy whether two material points coincide or not; indeed, two material points cannot coincide with each other. It is altogether different when one point is material and the other only an optical image; in such a case actual coincidence is possible, and it is easy to see whether there is actual coincidence or not, especially if we use a microscope to magnify the cross wires, in which case the coincidence of the image S′ of the distant point S, with the intersection of the cross wires, may be seen with wonderful distinctness.

347 The great advantage of the camera obscura, fig. 103, over the two sights, fig. 102, for the purpose of ascertaining the direction of the distant point S, is now manifest. In one case the eye has to look whether two points,

that are really at some distance from each other, appear to coincide or not, which it is impossible accurately to determine, because the eye cannot see distinctly two objects at different distances from it at the same time. In the other case the eye has only to see whether an optical image formed on a screen actually coincides with a mark on that screen or not, which may be done with the greatest exactness.

In order, then, to determine accurately the direction in which any distant luminous point S is seen, we have only to point the instrument represented in fig. 103 towards S, and move it carefully until the image of S, which will be seen on the semi-transparent screen C D, coincides exactly with the point of intersection of the cross wires. Then the line drawn from that point through the point H—i. e., the line of collimation, must point directly to S. In this manner the direction in which S is seen is ascertained.

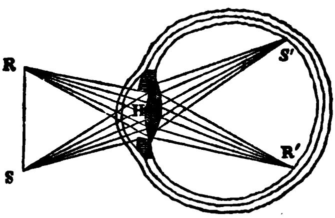
348 By using a microscope to magnify the cross wires, this may be done, as we have stated, with extraordinary accuracy. When a microscope is attached to the instrument for this purpose, the whole compound instrument so formed becomes the regular astronomical telescope. We shall now say a few words respecting the proper kind of microscope, or *eye piece*, as it is generally called, which is thus employed.

IV. *Of the Eye Piece, or Microscope.*

349 *Simple Microscope.*—By looking through a convex lens, placed close to the eye, we may see objects distinctly much nearer to the eye than we could do without such assistance. Now, the nearer an object is, the larger it appears, and therefore a convex lens thus used will enable us to see an object larger than it can possibly appear to the naked eye.

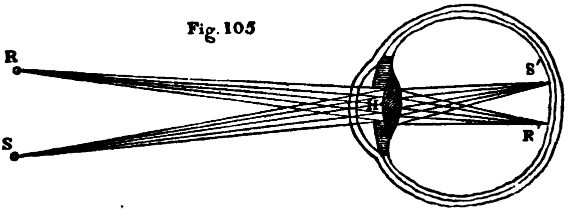
To explain this point the better, let us suppose that the naked eye cannot see an object distinctly nearer than six inches, and that the focal length of the convex lens is one inch; then, if we place the object at an inch from the eye, and look through the lens at it, we shall see it distinctly; for, as we have explained above, rays diverging from a point whose distance from a lens is equal to the focal length, emerge from the lens parallel to each other, and therefore are brought to a focus on the retina by the action of the lenses of the eye, as has been stated above. Hence, the effect of the convex lens is simply to enable us to see an object placed at a distance of one inch from the eye, which could not be seen without the lens nearer than six inches. The result of this will be, that the object will appear, when seen through the lens, six times larger than when seen by the naked eye.

Fig. 104



350 This will be seen by comparing figs. 104 and 105; in the former, R S, the object, is supposed to be one inch from the eye; in the latter, R S is supposed to be six inches from the eye. The image of R S on the retina is found by considering that it is produced by the lenses of the eye, in the same manner as the image on the screen in the camera obscura by the lens in the hole; and therefore if we suppose H to be the centre

Fig. 105



of the lenses of the eye, we have only to draw straight lines from S and R through H, to meet the retina at S′ and R′, and then S′ and R′ will be the points where the rays from S and R respectively are brought to a point on the retina. This being the case, it immediately follows, that if R S be six times farther from H in fig. 105 than it is in fig. 104, the size of the image, R′ S′, will be six times greater in fig. 104 than it is in fig. 105.

Now, in fig. 104, the eye, unassisted, cannot see R S distinctly, because the rays diverge too much, and the lenses of the eye will not be powerful enough to make them converge to the points R′ and S′ on the retina. Therefore the convex lens above spoken of will be necessary to make the vision distinct, by helping the lenses of the eye to overcome the great divergency of the rays, and make them converge with sufficient rapidity to form an unconfused image on the retina.

351 A very simple way of showing the truth of this account of the manner in which a lens placed close to the eye magnifies, is to look at the object R S, fig. 104, through a pin hole in a card, instead of through a convex lens. The hole, like the lens, will evidently diminish the divergence of the rays, and therefore assist the lenses of the eye. Of course the hole greatly weakens the brightness of the image, because it cuts off a great portion of the rays, or rather, allows only a small portion of them to enter the eye; but still it makes the object distinctly visible, and, as we have explained, magnifies it by enabling the eye to see it so much nearer than it could do without the hole.

352 To try this experiment, it is only necessary to look at small print through the hole in the card, placed very close to the eye; it will be found that we may, by so doing, bring the print within a few inches of the eye, and still see it distinctly, though it will not appear strongly marked, on account of the small quantity of light allowed to pass by the hole. The card should then be removed, keeping the eye still at the same distance from the print, and it will be perceived immediately how much the hole assisted in making the vision distinct; for the moment the card is removed, the print will become utterly confused and indistinct, so that one letter cannot be distinguished from another.

353 A convex lens used in this manner, that is, put close to the eye, is called a *simple microscope*. It is important to remember that a lens thus used magnifies simply by enabling the eye to get nearer to the object than it could do naturally, and this it does by helping the lenses of the eye to overcome the increased divergence of the rays.

354 *Vision through a Lens not placed close to the Eye.*—There is a very important difference in the action of a lens *not placed close to the eye,* from that we have just explained, as we shall now show.

Fig.106

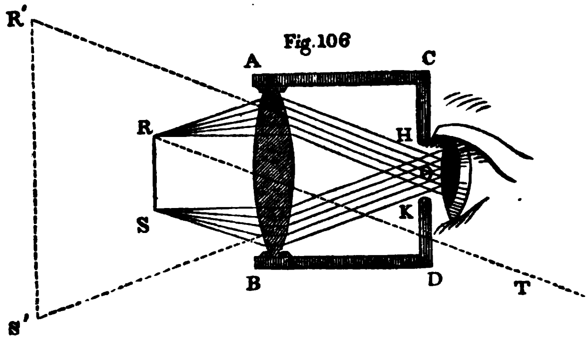


Fig. 106 represents a short tube A B C D, at one end of which is a lens A B, and at the other a hole H K, not much larger than the pupil of the eye:

it is called the *eye hole*, the eye being always placed close behind it, as is represented in the figure. R S is any object placed before the lens at a distance equal to the focal length. The use of the tube A B C D, and the hole H K, is to keep the eye always at a certain distance from the lens.

The course of the rays which enter the eye from the two points R and S is shown in the figure. The rays from R falling on the lens will emerge parallel to each other, or nearly so, because the distance of the object from the lens is equal to the focal length; but the ray R T, through the centre of the lens, will suffer no deviation; therefore the other rays, after emerging from the lens, will be parallel to R T, and those which are allowed to pass through the hole will enter the eye. To find the rays which pass through the hole, we have only to draw lines towards the lens from H and K parallel to T R, and all the rays between these two lines will get through the hole. Hence the rays drawn in the figure, and those only, will get through the hole to the eye; all the rest will be stopped by the tube. The course of the rays from S is exactly similar to that of the rays from R.

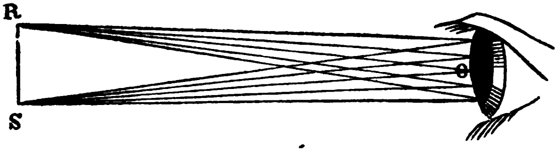
355 Now this being the case, it is evident that the lens A B discharges a two-fold office.

1st. It diminishes the divergence of the rays, and so assists the lenses of the eye to make them converge to points on the retina. It therefore so far acts in the same manner as the simple microscope.

2ndly. It magnifies the object, not merely by enabling the eye to get closer to it, but also by bending all the rays in the manner shown in the figure. This is a point of considerable importance, as will appear more clearly when we come to speak of the telescope; for in the telescope the rays, without the action of a lens thus disposed, would enter the eye almost perpendicularly, and the image would appear very small, or rather, very little of it would be seen.

356 The degree in which this instrument magnifies the object R S will appear better by comparing the vision through it with vision by the naked eye. In fig. 107, R S is supposed to be viewed by the naked eye; the point O in this figure, and in fig. 106, representing the centre of the lenses of the eye; the dotted lines R′ O and S′ O are the central rays which enter the eye from R and S produced backwards; the distance of R′ S′ from the eye in fig. 106, is supposed to be about one foot, and R S, in fig. 107, is also supposed to be about one foot from the eye. We say a foot, because at that distance the eye may see an object distinctly without any exertion; in fact, in reading small print, a person with good eyes would naturally hold his book at that distance, or thereabouts, from the eye. The eye could see an object at six inches, but not without fatigue.

Fig. 107

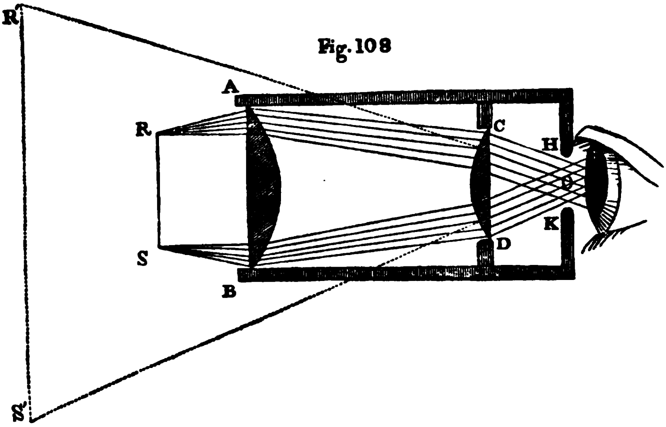


Now, in fig. 106, if we supposed the instrument removed, the points R′ and S′ would evidently be seen by the eye in the same directions as the points R and S appear to be when seen through the instrument; in other words, the object R S appears, when seen through the instrument, to be of the same size as the object R′ S′ seen by the naked eye. As far, then, as apparent size is concerned, we may substitute the object R′ S′ seen by the naked eye, in place of the object R S seen through the instrument.

Then, since R′ S′, fig. 106, and R S, fig. 107, are at the same distance from O, and since the images of these two objects on the retina are found by drawing straight lines from them through O to meet the retina, it is manifest that those images will be exactly proportional in size to the objects respectively. If, for instance, R′ S′ be ten times R S, the image on the retina in fig. 106 will be ten times larger than that in fig. 107; if R′ S′ be twenty times R S, the former image will be twenty times the latter, and so on.

357 Hence the degree in which this instrument magnifies is obvious; at the same time we must observe, that the above explanation is to be received merely as a general account of the nature of the magnifying power of the instrument; for the eye in judging of magnitude is greatly influenced by a variety of circumstances which we have not time to speak of here. This instrument is the *astronomical eye-piece* in its simplest form.

Fig. 108

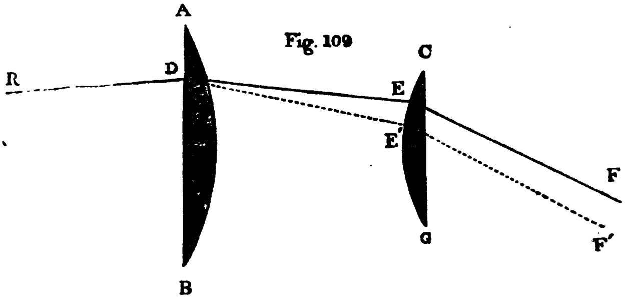


358 *The Compound Eye-Piece.*—This is shown in fig. 108. It consists of two lenses instead of one, but in other respects it is exactly the same as the simple eye-piece just explained. It is, however, a much more perfect instrument, and its optical effect, when well made, is almost faultless. The front lens A B is called the *field-glass*, because it enables us to see a greater extent of the object R S distinctly, than we could possibly do with the single lens, fig. 106. The extent of the object visible through the instrument is commonly called the *field of view*, and hence the name *field*-glass. The lens C D being next the eye, is called the *eye-glass*. The light coming from the object R S is bent by each of the lenses, as shown in the figure, and enters the eye as if it came from a larger object R′ S′. All that we have just said respecting fig. 106 applies, therefore, equally well in this case.

359 *How the Compound Eye-Piece is made Achromatic.*—One great defect of the single lens, fig. 106, is, that it is not achromatic; in consequence of the different refrangibility of the different colours, the image seen by the eye is imperfect and confused, the violet being more magnified than the red, and the intermediate colours in an intermediate degree. In the compound eye-piece this defect is remedied in the following manner:—

In fig. 109, A B and C G are the two lenses, and R D is any ray from the object incident on the field-glass at D. This ray is of course separated into its component colours by the dispersion which inevitably accompanies refraction (except the lens be compound). The violet ray will be more bent than the red, so that the former will fall below the latter, as is shown in the figure, where D E represents the red ray and D E′ the violet.

But the consequence of this will be, that the violet ray will fall on the second lens nearer the central part than the red ray, and therefore so far the second lens will produce a less effect on the violet than on the red ray; for the nearer to the central part a ray is incident on a lens, the less is it bent by the lens. Hence, if the two lenses be at a sufficient distance from each other, the fact that the violet is more refracted than the red by the first lens, and less by the second, may lead to a mutual correction between the two lenses—i. e., the under refraction of the second may just correct the over refraction of the first. This, it may be shown, will take place when the distance between the two lenses is half the sum of their focal lengths. When the lenses are so placed, it is found that the red and violet, and the other colours, emerge from the second lens parallel to each other, and are all caused to converge to the same point of the retina by the action of the lenses of the eye; for the lenses of the eye are so far achromatic that they always cause parallel rays, whether of different colours or not, to converge to the same point on the retina.



360 This eye-piece was the invention of Huygens, but the principle upon which it acts was pointed out by Boscovich. In astronomical instruments this eye-piece cannot be used in its perfection on account of its being necessary to have the object R S too close to the field-glass, whereby every spot and flaw in that glass is made visible, and spoils the clearness of the field of view. To remedy this defect, Ramsden placed the lenses a little closer to each other, and so was enabled to keep the object R S at a greater distance from the field-glass. The lenses are each of the same focal length in Ramsden's eye-piece; they are also plano-convex—i. e., convex with one side plane, the convex surfaces being turned towards each other, as is shown in the figure.

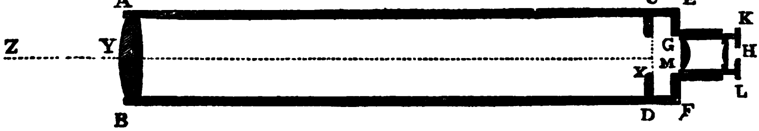
361 The compound eye-piece has many other advantages over the simple one represented in fig. 106, chiefly arising from the refraction in the former being divided, as it were, between two lenses, instead of being entirely effected by one; but we have not space to say more on the subject.

V *Of the Astronomical Telescope.*

362 It will now require but a few words to explain the construction of the astronomical telescope; it is, in fact, nothing more than the camera obscura represented in fig. 103, with the addition of Ramsden's eye-piece, to enable the eye to see more accurately whether the image of a distant luminous point, formed on the semi-transparent screen, coincides with the centre of the cross wires or not. Furthermore, the screen is either removed or made transparent, as its semi-transparency is of no use where an eye-piece is used to view the image and the cross wires, and only has the effect of diminishing the brightness of the image. It would be absolutely necessary to retain the semi-transparent screen, if a simple microscope were used instead of an eye-piece, for without the semi-transparent screen the rays that would get into the eye through a lens placed close to it would be only those which come from the central part of a distant object, so that the field of view would be extremely limited. But with an eye-piece, if the eye-hole is placed in the proper position, the rays from a comparatively great extent of a distant object are brought to the eye.

363 Fig. 110 represents the astronomical telescope. A E F B is the tube, and C D is the screen, which in the camera obscura above described was semi-transparent, but is now supposed to be perfectly transparent; it may be a piece of plate glass with two fine cross lines drawn upon it, or it may be simply a round hole in a piece of brass fixed inside the tube, with two extremely thin wires drawn tight across it. At A B is the lens which produces the image of any distant object at which the telescope is pointed, which image must be formed exactly at the transparent screen or hole C D, where the cross lines or wires are placed. This lens is called the *Object Glass*, and is, of course, achromatic and aplanatic, so as to form a perfectly distinct and well-defined image of the object.

Fig. 110



X is the point of intersection of the cross lines or cross wires, which are supposed to be so fine and delicate that the point X is defined by them in the most perfect manner possible.

Two intersecting lines are found to form the best kind of mark for defining a particular point in the interior of an instrument· these lines are generally at right angles to each other. but they are sometimes made to intersect obliquely.

Y is the centre of the object glass corresponding to the hole H in fig. 103, and the imaginary straight line X Y Z, drawn from X through Y, is the *line of collimation*, which we have spoken of before. This line is the great and principal thing to be attended to in the instrument. The instrument itself is nothing but a contrivance for pointing this line very accurately towards any particular star or distant luminous point. When the line of collimation points towards any star, an image of that star is seen to coincide exactly with X, the centre, or point of intersection, of the cross wires, and this is the test whereby we know whether the line of collimation points in the proper direction or not.

G M K L is the eye-piece (Ramsden's) already described, the use of which is simply to magnify the image of the star and the cross wires, and so enable the eye to judge the better whether that image is exactly at the point X or not. This eye-piece is capable of sliding in a tube attached to the large tube, as shown in the figure, for the purpose of accurate adjustment, and for adapting the vision to eyes of different powers.

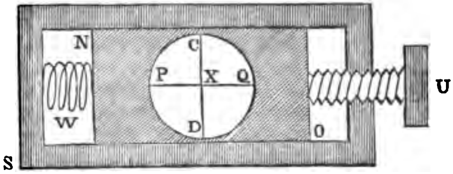
364 It is important to observe that there is no connexion whatever between the line of collimation and the eye-piece; the eye-piece may not be placed quite straight, or it may distort the image and the wires, which it always does to a certain extent; but if it shows the image of the star distinctly coincident with the centre of the cross wires, we may be sure that the line of collimation points exactly to the star.

365 It is also necessary to remark that the cross wires need not be placed exactly in the middle of the tube, they may be moved a little to one side or the other if necessary; though it is better that their intersection X should be as nearly as possible opposite to the centre of the object glass Y, in order that the line of collimation may be perpendicular to the object-glass, or very nearly so.

366 *Adjustment and Movement of the Cross Wires.*—The piece of plate glass on which the cross lines are drawn (or, what is the same thing, the piece of brass with a circular hole, across which the cross wires are fixed) is generally made capable of movement backwards and forwards across the instrument, in the following manner:—

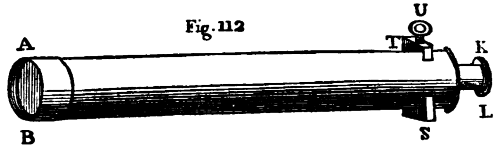
C Q D P, fig. 111, represents the piece of plate glass, having the cross lines C D P Q traced upon it. It is fixed in a flat piece of brass N O, with a circular hole C Q D P. If there is no piece of glass, the lines C D and P Q are simply wires fixed tightly across this hole. The piece N O slides in a frame of brass S T. A screw U, and a spring W, act upon the piece N O, in the manner shown in the figure, so that by turning the head of the screw U, the piece N O is caused to slide in the frame S T towards S, and by the opposite motion of the screw the spring W acts upon N O, and makes it slide the opposite way. Sometimes, however, instead of the spring W there is another screw, the counterpart of U, and by means of the two screws the piece N O is moved at pleasure, and kept fixed if necessary. The two screws are used instead of the screw and spring, where it is not necessary to move the piece N O, except occasionally by way of adjustment.

Fig. 111



The frame S T pierces the tube of the telescope, and is fixed across it near the eye end, in the manner shown in fig. 112, where A B K L is the telescope, A B the object glass, K L the eye-piece, S T the frame shown in fig. 111, and U the screw, by which the piece N O (fig. 111) is moved.

Fig. 112

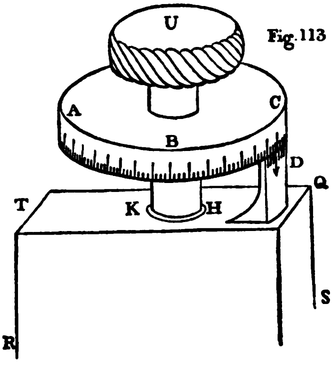


In this manner we may, by turning the screw U one way or the other, move the cross wires backwards or forwards across the tube of the telescope, and so adjust the point of intersection of the wires in its proper position, as will be explained presently.

VI. *The Micrometer.*

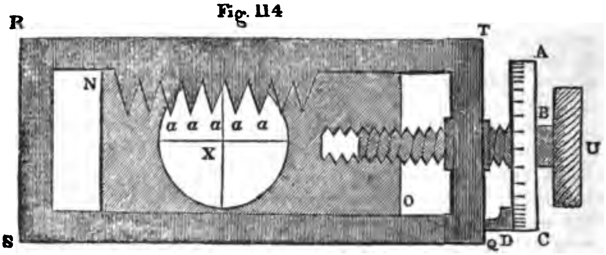
367 Where it is required to measure the image formed by the object glass, the thread of the screw U is formed with great accuracy, and the motion of N O is made as steady and even as possible. The head of the screw is also graduated, as shown in fig. 113, where T Q R S is a portion of the frame, H K the screw, working through the end T Q of the frame; U A B C is the head of the screw, consisting of two parts—namely, a milled or grooved circle U, which the fingers lay hold of in order to turn the screw, and a graduated circle A B C, the graduations being shown in the figure on the rim of this circle. D is the index, which is fixed to the end of the frame T Q, and which just touches the graduated circle, without, however, impeding its motion. The screw in this case does not work exactly in the same manner as that shown in fig. 111; for it is necessary, evidently, that it should move the piece N O after the manner of an endless screw—that is, the female screw is not in the frame as in fig. 111, but in the piece N O. In this way the screw itself does not move in and out when it is turned round.

Fig. 113



This is shown in fig. 114, which represents a section of the micrometer; where A B C U is the head of the screw, R S Q T the frame in which the piece N O moves; the end of the screw piercing the piece N O. D is the index, which is attached to the end of the frame T Q.

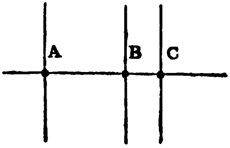
Fig. 114



368 *a, a, a, a,* &c. represent a set of brass points equidistant from each other, projecting from the upper side R T of the frame. These points are seen in the field of view, along with the cross-wires: the use of them is to help in counting the number of turns we give to the screw in any case. When the screw is turned round, the vertical cross-wire passes each of these points in succession, and they are placed at such distances, that one turn of the screw makes the vertical cross-wire move from one point to the next. It is not necessary that these points should be placed with great exactness, as they only serve to count the number of turns given to the screw.

369 An example will best show the use of this micrometer. We shall suppose that A B and C (fig. 115) are three stars, or rather, images of stars, seen on the horizontal cross-wire, and that we wish to measure their relative distances from each other. We shall also suppose that there are 100 graduations on the head of the screw, which are numbered 0, 1, 2, 3, 4, &c. in order. By means of these graduations, we can tell how much we turn the head of the screw; for every graduation that passes the index D, as we turn the screw, corresponds to the hundredth part of a complete revolution.

Fig. 115



Suppose now, that we turn the screw until the vertical wire is brought to meet the star A, and that the graduation seen at the index D is ten. Let us then turn the screw until the vertical wire comes to the star B, and suppose that as we do this the vertical wire passes across four of the points *a, a, a, a,* and that the graduation seen at D, when the wire comes to B, is thirty-five. Then it follows, the motion of the wire from A to B corresponds to four complete turns of the screw, and twenty-five graduations, or twenty-five hundredth parts of a complete turn.

In like manner, let us move the wire from B to C, watching the points and looking at the graduations at D, when the wire comes to C; and suppose that the number of points the wire passes across is two, and the graduations forty. Then the motion of the wire from B to C corresponds to two complete turns of the screw, and five graduations.

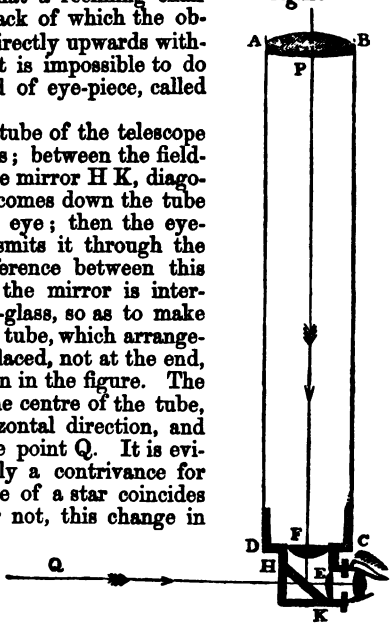
Hence it follows, that the distance A B is to the distance B C as four units and twenty-five hundredth parts of unity to two units and five hundredth parts—that is, A B is to B C as 4·25 to 2·05.

370 From this example the use of the micrometer is manifest. The above is but a rude representation of the simplest kind of micrometer; there are many details and niceties in the construction, which we could not give without entering into the subject more at length. There are several other kinds of micrometers, nearly all, however, depending on the principles above explained, and consisting of various contrivances for measuring the image seen in the focus of a telescope, by means of the motion of a graduated screw.

VII. *The Diagonal Eye-piece.*

371 Before we leave the telescope, we must mention the *diagonal eye-piece,* which is indispensable in small instruments. It is often necessary to look through a telescope at stars near the zenith, and this requires the head of the observer to be placed in a very inconvenient position, except the instrument be so large that a reclining chair may be placed under it, upon the back of which the observer may lay his head, and look directly upwards without fatigue. In a small instrument it is impossible to do this, and therefore the following kind of eye-piece, called diagonal from its shape, is used.

Fig. 116



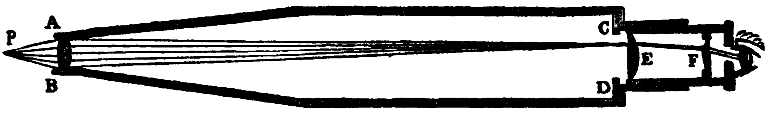
A B C D, fig. 116, represents the tube of the telescope pointed upwards, and F the field-glass; between the field-glass and eye-glass is placed a plane mirror H K, diagonally, so as to reflect the light which comes down the tube in a horizontal direction towards the eye; then the eye-glass E receives this light, and transmits it through the eye-hole to the eye. The only difference between this and the common eye-piece is, that the mirror is interposed between the field-glass and eye-glass, so as to make the light emerge at right angles to the tube, which arrangement requires the eye-glass to be placed, not at the end, but at the side of the tube, as is shown in the figure. The ray of light P F which comes down the centre of the tube, is reflected by the mirror in a horizontal direction, and enters the eye as if it came from the point Q. It is evident that, since the eye-piece is only a contrivance for better ascertaining whether the image of a star coincides with the centre of the cross-wires or not, this change in the form of the eye-piece does not, in any way, alter the nature of the instrument, but simply enables the eye to look at the wires and image horizontally intead of vertically.

372 The diagonal eye-piece is made capable of sliding on or off the instrument at pleasure, so that it may be used whenever occasion requires it. Good telescopes have generally several eye-pieces, or *powers,* as they are called by opticians, of different magnifying power, which may be employed according to the nature of the observations, and the state of the atmosphere.

VIII. *Of the Astronomical or Reading Microscope.*

373 We need say but little here respecting the miscroscope, as we have already stated what the simple microscope is, and the compound miscroscope is precisely the same instrument as the telescope; being, in fact, a telescope, if we may so use the word, employed to view near instead of distant objects. Dr. Goring has proposed to call the compound microscope by the name *engiscope,* which well expresses its nature, as compared with the *telescope;* the former word signifying that which views *near,* and the latter distant, objects.

Fig. 117



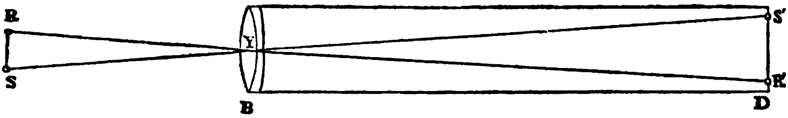
374 The compound microscope is shown in fig. 117, with the course of the

rays, which come from a near luminous point P, through the instrument. The tube A B C D, tapers towards the object end A B, because the object glass, being of high power, is necessarily small. The object glass is of high power, in order that it may be able to overcome the great divergency of the rays coming from an object so near as P, and make them converge to a focus at C D, which, as in the case of the telescope, is supposed to be a piece of plate glass with cross lines drawn upon it, or simply a hole in a brass plate with cross wires stretched across it. The eye-piece consists of a field-glass, eye-glass, and eye-hole, and is, in fact, precisely the same that has been described in the case of the telescope. In microscopes which are used simply for magnifying, but not measuring, a different eye-piece is used—namely, Huygen's eye-piece, above alluded to.

375 This instrument, though precisely the same in principle as the telescope, differs from it in one important particular—namely, that in the miscroscope, the image formed at C D is always much larger than the object, whereas, in the telescope, it is much smaller. We may show this very easily as follows:—

Let A B C D, fig. 118, represent the telescope, at least the telescope without

Fig. 118

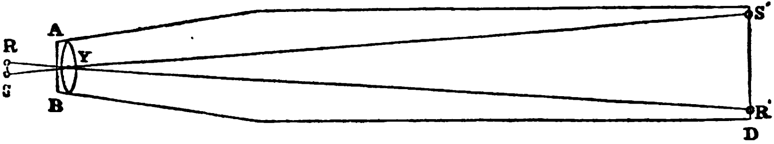


the eye-piece, which we do not now require to consider; C D the screen, Y the centre of the object glass, and R S a distant object, but which, for want of room on the paper, must necessarily be drawn near. Then R' S', the image of R S, formed at C D, is found by drawing straight lines from R and S through Y, to meet C D at the points R' and S'; from which it is evident that R' S' bears the same ratio to R S that the length of the tube does to the distance of R S from Y; for instance, if the length of the tube be three feet, and R S be 3000 feet from Y, it is evident that R' S' will be 1000 times smaller than R S.

Now, in the telescope R S is always a distant object, and therefore the image R' S' formed by the object glass is always considerably smaller than the object R S.

In the microscope this is reversed, as is evident immediately from fig. 119;

Fig. 119



where the image R' S' is found as before, by drawing straight lines from R and S through Y, the centre of the object glass A B, to meet C D at R' and S'. Now, here R S is very close to Y—in some of the good instruments lately made, the distance may not be more that $\frac{1}{12}$th of an inch*—but suppose we call it an inch, and assume the length of the tube to be six inches; then it is clear that R' S' will be six times greater than R S.

376 In both the telescope and microscope, the eye-piece magnifies in the manner we have explained; hence, in the telescope, the eye-piece alone

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* In this case the object glass is a *triple achromatic*, consisting of six lens altogether, united in pairs.

magnifies, but in the microscope both the object glass and the eye-piece magnify.

377 From what has been just explained, it is clear that, *cœteris paribus*, the magnitude of the image R′ S′ in both instruments is proportional to the length of the tube; the longer the tube, therefore, the greater the magnifying power of the instrument.

378 In the microscope, the size of the image is evidently increased by bringing the object R S nearer to the object glass: to do this, the power of the object glass must be increased, for it must be sufficient to overcome the divergence of the rays, and make them converge to a focus at C D. Now, when the object is placed at a distance from the object glass equal to its focal length, the power of the glass is then just sufficient to overcome the divergence of the rays, and cause them to emerge from the lens parallel to each other: hence, to make the rays converge to a focus at C D, either the object glass must be made a little more powerful, or the object must be moved a little farther from the lens, in order to diminish the divergence of the rays a little.

It appears, then, that the distance at which the object must be placed from the object glass of a microscope is a little greater than the focal length of that glass.

379 Great improvements have of late been made in the manufacture of object glasses for microscopes, which are now ground, polished, and centred in their proper positions, with perfectly wonderful accuracy. Object glasses are now made of a focal length of $\frac{1}{12}$th of an inch, which are capable of overcoming a divergence of 120° in the incident rays, and bringing them to an accurate focus at C D.

380 *The Reading Microscope.*—The *astronomical* or *reading* microscope, which is used for reading and subdividing the graduations in large instruments, is a compound microscope, with a micrometer such as that we have above described. Each graduation of the instrument is generally about $5'$; five complete turns of the screw move the wire of the micrometer from one graduation to the next, and the graduated head of the screw is divided into —suppose sixty graduations. In this manner each graduation of the screw corresponds to $1''$.

381 As the reading microscope is a very important part of several useful instruments, we must explain the manner in which it is used. In fig. 120,

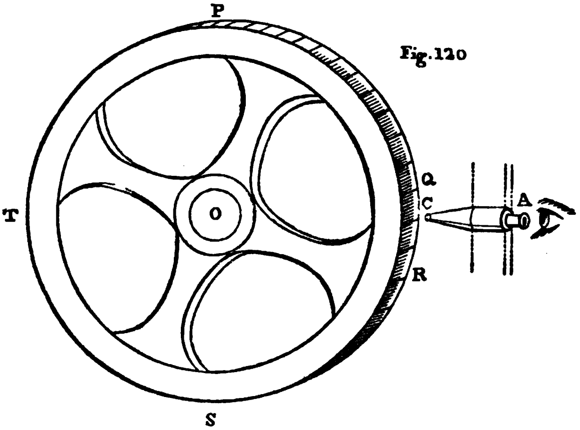


Fig. 120

P Q R S T represents a graduated circle capable of moving about its centre O. The graduations are supposed to be engraven on the rim of this circle, as shown in the figure, and they are viewed by a fixed microscope A C. The whole rim P Q R S T is divided into 360 equal parts, and each part subdivided into twelve equal parts, so that each of these subdivisions is the twelfth part of a degree, or 5′. The microscope is furnished with a micrometer and graduated screw, as above described, the graduated head of the screw being divided into 60, or 120, or 240, or 300 equal parts—say 60, for simplicity.

Fig 121

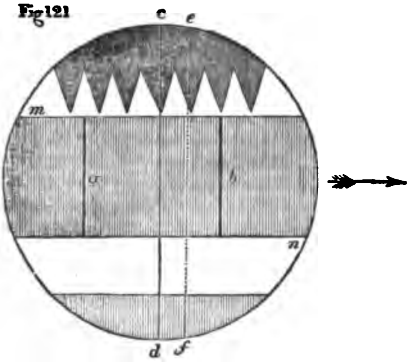


Fig. 121 shows the field of view of the microscope—i. e., what the eye sees on looking through it. *m n* is a portion of the rim P Q R S T of the instrument seen in the microscope, and, of course, greatly magnified; *a* and *b* are two consecutive graduations of the rim, so that the space *a b* is the image of 5′ of the rim formed in the focus of the microscope; C D is a fixed wire, parallel to the graduations *a* and *b*, and firmly fixed in the focus; *e f* is another parallel wire—viz., that which is moved by turning the screw of the micrometer, as above explained. Points are seen on the field of view, to help in counting the number of complete turns of the screw, as we have described before.

The fixed wire *c d* serves as a mark, and the moveable wire *e f* serves to measure the space between this mark and the next graduation *a* or *b*. Five complete turns of the screw move *e f* from *a* to *b*, that is, over a space of 5′; therefore, one turn moves *e f* over a space of 1′, and the sixtieth part of a turn moves it over a space of 1″.

Suppose now that the circle P Q R S T is turned round, and we wish to find out through how many degrees, minutes, and seconds we have turned it. Let the hinder graduation *a*, seen in the microscope before moving the rim, be 20° 10′, and therefore the graduation *b*, 20° 15′, and suppose that it requires two turns and four sixtieth parts of a turn of the micrometer screw to make the wire *e f* move from *a* to *c d*; then it is evident that if the rim were divided so minutely as to show seconds, the graduation opposite the mark *c d* would be 20° 12′ 4″; for *a* is 20° 10′ and it is 2′ 4″ farther to *c d*, as shown by the micrometer screw. After the rim has been moved, suppose that the hinder graduation *a* seen in the microscope is 43° 35′, and that it takes three turns and twenty-four sixtieth parts of a turn of the screw to move *e f* from *a* to *c d*; then the graduation of the rim opposite the mark *c d* is 43° 38′ 24″, *a* being 43° 35′, and *c d* being 3′ 24″ farther on.

Since, then, the graduation opposite the mark is 20° 12′ 4″ before, and 43° 38′ 24″ after turning the rim, it follows that the difference—namely, 23° 26′ 20″—is the number of degrees, minutes, and seconds through which we have turned the rim.

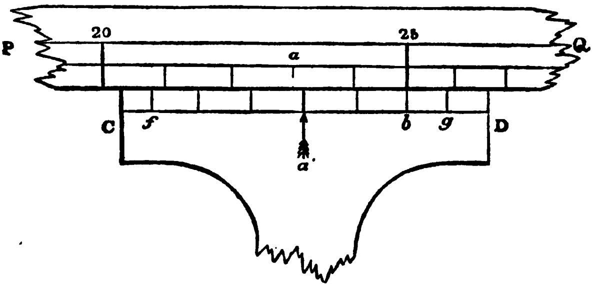
382 Thus the use of the reading microscope is obvious; for though the rim is only divided to 5′, we can read off and observe as accurately as if it were divided to seconds. Now, to divide the rim of a large instrument accurately to 5′—that is, into twelve times 360 exactly equal parts—is no easy matter, and costs a large sum of money; it is easy, then, to conceive what it would be to divide it to seconds—that is, into 60 × 60 × 360 equal parts—if the engraving of such a number of lines so close together were possible. Hence the importance of the reading microscope is obvious.

IX. *Of the Vernier.*

383 We must here briefly describe a very useful contrivance called the Vernier, from the name of the inventor, which takes the place of the reading microscope in smaller instruments, being much less expensive.

Let P Q, fig. 122, be a portion of the rim of a graduated circle, similar to that we have just described, which we shall suppose to be divided into 360 equal parts, each part being therefore 1°. In the figure these graduations are shown from 20° to 27°. C D represents the Vernier, which, in this case, is supposed to be fixed: it consists of a short graduated piece of brass or other substance, the graduation extending from *f* to *g*, and in the present instance we shall suppose them to be six in number; the graduated edge of the Vernier lies as close as possible to that of the rim, without preventing the motion of the rim round its centre.

Fig. 122



a' is the mark corresponding to the fixed wire *c d* in the reading microscope, (fig. 121.) Our object is to find what graduation of the rim is exactly opposite this mark.

Now, if the graduation *a* of the rim were exactly opposite *a'*, we should have no difficulty in doing this, for it is manifest that the arrow would then point at 23°; but this is not the case; *a* is a little behind *a'*, and before we can tell at what graduation *a'* points, we must find what fraction of a degree it is from *a* to *a'*.

To do this, suppose that the six graduations of the Vernier, from *f* to *g*, are exactly equal to five graduations of the rim, so that, if *f* were opposite 20°, *g* would be opposite 25°. Furthermore, suppose that the graduation *b* of the Vernier is just opposite 25, then six graduations of the Vernier are equal to 5°, and therefore one graduation is the sixth part of 5°—i. e., 50′—consequently from *a'* to *b* is twice 50′ or 100′; but from *a* to *b* is twice 60′ or 120′; therefore, from *a* to *a'* is the difference between 120′ and 100′—that is, 20′. It appears, therefore, that the mark *a'* points to 23° 20′.

Hence the principle of the Vernier is obvious; it enables us to find at what graduation of the rim the mark *a'* points, though none of those engraven on the rim may be exactly opposite *a'*.

384 Generally, to find how far it is from *a* to *a'* we have the following rule:—Look for that graduation of the Vernier which is exactly opposite a graduation of the rim; count on the Vernier what number of graduations it is from that graduation to *a'*; multiply 10′ by that number, and then the result is the number of minutes from *a* to *a'*. 10′ in this case is the difference between a graduation of the Vernier and a graduation of the rim, one being 50′, the other 60′. In every case the distance from *a* to *a'* is found by multiplying this difference, whatever it may be, by the number of graduations from *a'* to *b*.

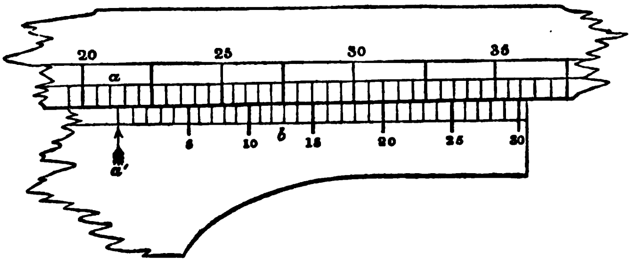
385 If the Vernier consist of thirty graduations, and these thirty graduations are equal to twenty-nine graduations of the rim; and further, if the whole rim be divided into twice 360 equal parts, so that each division is half

a degree or 30′, then each division of the Vernier will be the thirtieth part of twenty-nine half degrees, or, what is the same thing, each division of the Vernier will be 29′. In this case, suppose that the graduation *b* of the Vernier, which is exactly opposite a graduation of the rim, is ten graduations from the mark *a′*; then from *a* to *b* will be 10 times 30′, or 300′, and from *a′* to *b* will be 10 times 29′, or 290′; and therefore from *a* to *a′* will be the difference—that is, 10′. In like manner, if the graduation *b* of the Vernier be twenty graduations from *a′*, the distances from *a* to *b* and from *a′* to *b* will be respectively 20 times 30′, and 20 times 29′; and therefore the distance from *a* to *a′* will be clearly 20′. And, in general, the distance from *a* to *a′* will always be as many minutes as there are graduations from *a′* to that graduation of the Vernier which is opposite one of the rim.

386 If there be no graduation of the Vernier exactly opposite one of the rim, we must in place of it look for that graduation which is *most nearly* opposite one of the rim. In this case we shall be subject to a small error, not, however, exceeding 30″ in the case just described.

387 The graduations of the Vernier are always numbered, beginning from *a′*, as is shown in fig. 123. There should always be a lens or simple microscope attached in some convenient way to the Vernier, in order to magnify the graduations, and make it more easy to see what graduation of the Vernier is exactly opposite one of the rim, or most nearly so.

Fig. 123



388 The Vernier shown in fig. 123 is one very frequently used; the rim being divided into half degrees, and the Vernier into thirty equal parts, which are together equal to twenty-nine half degrees; and the graduations of the Vernier are numbered, beginning from *a′*. In this case we have the following simple rule for reading off:—

Look for the graduation of the rim (*a*) which is just behind the mark *a′* of the Vernier; look also for the graduation (*b*) of the Vernier which is exactly, or most nearly, opposite one of the rim; then the number of minutes from *a* to *a′* is the number on the Vernier opposite *b*, and the mark *a′* therefore points to that graduation of the rim which is the number of degrees, or degrees and a half, shown on the rim at *a*, together with the number of minutes shown on the Vernier at *b*. In this manner, therefore, we read off very quickly the graduation the mark *a′* points at.

In fig. 123, *a* is supposed to be at 21° on the rim, and *b* is at 12 on the Vernier; therefore *a′* points at 21° 12′. If *a* were at $26\frac{1}{2}°$ on the rim, and *b* at 16 on the Vernier, the reading would be $26\frac{1}{2}° + 16'$, or 26° 46′.*

389 We have now sufficiently explained, for our present purpose, those optical principles which are most essential to be known in astronomy; we have also described the two great instruments, the telescope and microscope, by which the eye is enabled to judge so accurately of direction, and measure such small subdivisions of space. We shall now proceed to the Transit Telescope or Instrument.

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* The graduations in figs. 122 and 123 have not been made exactly equal to each other by the engraver, but the error does not affect the explanation.

CHAPTER VII.

THE TRANSIT INSTRUMENT.

I. *Description of the Transit Instrument.*

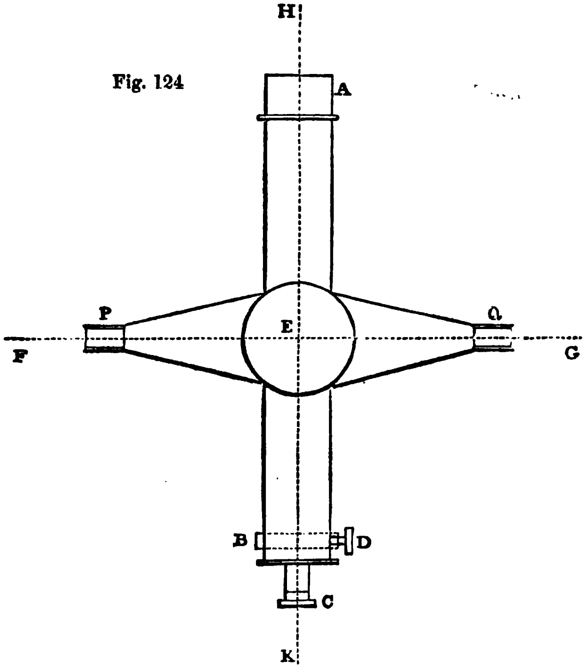
THE Transit Instrument consists of a telescope such as we have just described, mounted in such a way that the line of collimation may move freely in a vertical plane, which plane is generally the plane of the meridian, but sometimes the prime vertical plane, or some other vertical plane suitable to the observer's purpose.

The transit instrument may be said to be the most perfect, simple, and useful of all astronomical instruments: it is capable of the following important applications:—

1st. To determine the position of the meridian plane, and therefore the true points of the compass, at any place.
2nd. To determine the correct time at any place, and so to serve as a regulator of clocks and chronometers.
3rd. To determine the right ascension of any heavenly body.
4th. To determine the longitude of any place.
5th. To determine the latitude of any place.

When applied to any of the four former uses, the instrument is set in the meridian plane; but for the latter use it is set in the prime vertical generally.

Fig. 124



391 *The Pivots.*—The transit instrument consists of a telescope A B C, fig. 124, attached firmly to a perpendicular axis P Q, which is made of a conical shape on each side, in order to combine strength and lightness. The extremities P and Q of this axis are cylindrical, of the same size, and having

the same imaginary axis F G—that is, the imaginary line F G runs exactly through the middle of each cylinder P and Q, and the cylindrical surface of each runs exactly parallel to F G.

P and Q are called the *Pivots* of the transit instrument, and the imaginary line F G is called the *Axis of the Pivots*, or, what is the same thing, the *Axis of the Transit.* It is of the utmost importance that these pivots should be correctly made, as the goodness of the instrument depends mainly upon them. Three things are necessary to the perfection of the pivots—viz.,

1. They must be truly cylindrical.
2. They must have the same imaginary axis.
3. They must be equal in diameter.

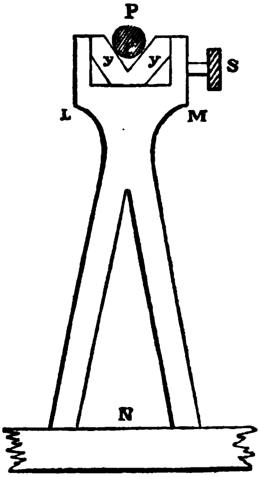
Hence it is obvious, that not only must great pains be taken by the workmen in turning these pivots so as to secure the above requisites, but the observer must take care when he uses the instrument to keep the pivots clean, and to preserve them from being indented in the least degree by any blow or rough handling. This caution is given, because it is necessary frequently to lift the pivots off their bearings, and put them down again.

392 *Bearings of the Pivots.*—The pivots do not turn in circular holes, as might at first be supposed, because circular bearings are not sufficiently steady, inasmuch as the circular hole in which a pivot turns must always be a little larger than the pivot, to allow of free motion. Instead, therefore, of circular bearings, the pivots are supported on forks, or Y's, as they are called, being of the shape of the letter Y, (see fig. 125,) or something approaching thereto.

Fig. 125

In fig. 126 is shown the manner in which the pivot P rests on its forked bearing y y, L M N being the pillar or stand to which the Y or bearing is attached. S is a fine screw, which, being turned, gives a horizontal motion to the Y, for the purpose we shall explain presently.* The other pivot Q is supported on a similar Y and pillar, only instead of having a fine screw such as S to move it horizontally, it has one to move it vertically up or down. P is called the *horizontal* Y, and Q the *vertical* Y.

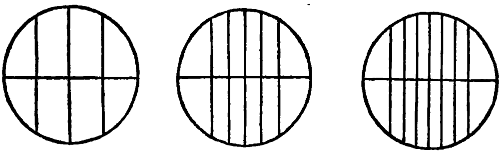
Fig. 126



393 *The Telescope.*—The telescope has cross wires in the focus such as we have described in the former chapter, which are moved horizontally by a screw D, in the manner we have explained. Generally, in small instruments, there are one horizontal wire and three vertical wires equidistant from each other, as is represented in fig. 127, but in large instruments there are five, and often seven, vertical wires.

There are three or four eye-pieces of different powers which slide in at C, one of which is

Fig. 127



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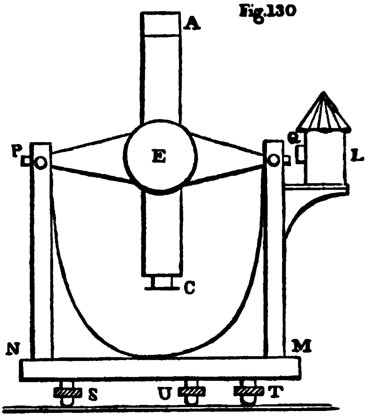
* We have represented S as an ordinary screw with a milled head; generally, instead of such a screw, there are two opposing screws, for the sake of greater steadiness, which are worked by a lever.

always a diagonal eye-piece—see former chapter. When we wish to use the telescope, we must slide in a suitable eye-piece, and move it in or out until the wires are seen distinctly, and sharply defined. We must then direct the telescope to a star, and if the star is also seen distinctly and well defined, the telescope is properly adjusted as far as the focus is concerned; if not, the wires in the focus must be moved in or out till the image of the star becomes well defined. If, on moving the eye a little to one side or the other of the eye-hole, the star appears to keep steadily on one of the wires, this shows that the focus is correctly adjusted.

394 *The Stand and Pillars.*—These are shown in fig. 130, where P N and Q M are the two pillars which support the Y's and pivots P and Q. A C is the telescope, N M is the base of the stand, which is generally circular, and, for greater steadiness, supported on three short legs S U and T, which have screws for shortening or lengthening them, in order to make the stand as nearly as possible horizontal, and therefore the pillars vertical. The pillars in large fixed instruments are made of stone, firmly imbedded in a hard foundation, but in small portable instruments they are of metal, firmly braced to the stand N M, so that they may not be capable of shaking or trembling.

Fig.130



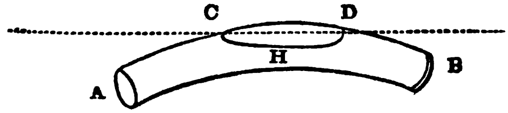
395 *Illumination of the Wires in the Focus.*—At night it is necessary to illuminate the wires, in order to make them visible. This is done by means of a lamp L, placed on a stand close to one of the pivots. The pivot is pierced, and the conical axis is hollow, so that the light from the lamp, passing through the hole in the pivot, enters the middle of the tube of the telescope at E. There is a plane reflector placed diagonally across the telescope tube at E, by which the light from the lamp is reflected down the tube to the focus, and in this manner the wires are illuminated. The reflector has a good-sized hole cut in the middle of it, so that it may not intercept any of the light which comes through the object-glass down the tube to the eye. The lamp has a moveable shade, by which the degree of illumination may be diminished, which is necessary when observing faint stars.

396 *Object of Mounting the Telescope in this manner.*—The object is, in the first place, to make the telescope move with great steadiness in a plane; this is effected by the long axis P Q; for it is evident that the longer the axis is, the less effect will imperfections in the pivots have in making the telescope move unevenly. In the second place, the bearings of the pivots are made moveable horizontally and vertically, by means of fine screws, as above described, in order to place the axis more accurately in any required position—as, for instance, in or perpendicular to the plane of the meridian; the stand is placed in the proper position at first, as nearly as can be judged, and then the further and complete adjustment of the axis is effected by the delicate motion of the screws.

397 *The Level.*—The transit instrument is always accompanied by a spirit level, for the purpose of making the axis perfectly horizontal. The construction and use of the level is as follows:—

A B, fig. 129, is a glass tube, slightly curved, and

Fig. 129



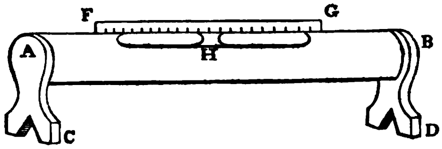
almost, but not quite, filled with alcohol, so that a bubble C D is left in the tube. This bubble will, of course, always ascend to the highest part of the tube, in whatever position it may be held, and so will serve as a mark of the inclination of the tube; for if the inclination be altered, the highest part is not where it was before, and therefore the bubble will change its position, since it must always ascend to the highest part of the tube.

The curvature of the tube, as shown in the figure, is considerably exaggerated, for the purpose of showing the nature of the level; in practice, the curvature is so small that the tube appears quite straight to the eye. The smallness of the curvature makes the least change of inclination of the tube evident; for the more nearly straight the tube is, the more does the bubble move when the inclination of the tube is altered. The tube is not made quite straight, because, if it were so, the moment one extremity was elevated in the least degree above the other, the bubble would immediately move to the former extremity—in fact, the instrument would then be too sensitive, and would require the tube to be placed always in a horizontal position with a degree of exactness not attainable in practice. This is the reason why a slight curvature is given to the tube.

398 The line C D joining the extremities of the bubble will be always horizontal if the tube be of uniform bore and curvature, otherwise, in consequence of capillary attraction, this will not be the case. However, the horizontality of this line is not by any means essential, for the principle of the instrument consists in this, that any change in the inclination of the tube to the horizon will be immediately shown by the motion of the bubble.

399 Hence we have the following conclusion upon which it will be seen the use of the level depends—viz., that if the bubble does not move when we change the position of the tube, it follows that the inclination of the tube to the horizon has not been altered by the change of position.

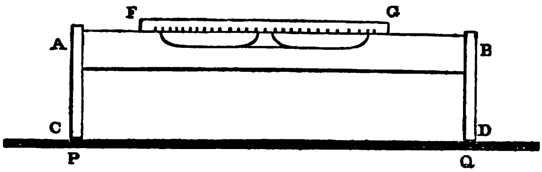
Fig. 128



400 The tube is fixed in a frame of brass A B, shown in fig. 128; the upper part of the frame is open so as to show the upper surface of the tube; on the top is a straight scale F G, marked with a number of equidistant vertical lines, the use of which is to enable the observer to note the position of the bubble with accuracy. The frame A B has two legs A C and B D of equal length, and cut at the bottom in the shape of inverted Y's, for the purpose of being placed upon the pivots of the transit instrument, the distance from C to D being the same as the distance between the two pivots, so that C may rest on one pivot, and D on the other.

401 From what has been above stated, it follows, that if we place the level with the legs C and D upon a rod or axis P Q, in the manner shown in fig. 133, and note the place of the bubble by looking at the scale F G; and

Fig. 133



this being done, if we change the position of the level by placing the leg C at the end Q, and D at P, and again note the place of the bubble; then, if the bubble is not in the same place as before, one of the extremities of the rod P Q must be higher than the other; but, if the place of the bubble is unchanged, the extremities must be exactly on the same level, and therefore the rod is horizontal. This is manifest: for, if one of the extremities, P or Q, be higher than the other, the above change in the position of the level evidently changes its inclination to the horizon, and therefore the bubble must move; but if one extremity of the rod is not higher than the other, then the change of position does not alter the inclination of the tube to the horizon, and therefore the bubble does not move.

II. *Examination and Adjustment of the Transit Instrument.*

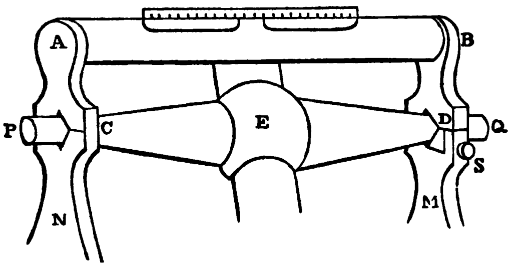
402 *Examination of the Transit.*—It is very important that an observer should be able to examine a new instrument he is about to purchase, to determine whether it is accurately constructed or not, and an instrument which has been for some time in use, to discover whether it has suffered any injury. The first thing to be looked to is the steadiness of the stand and pillars on which the instrument rests: they should be well braced together, and the three screws, or short legs on which the whole stands, should turn tightly, and be perfectly free from any tendency to shake. The Y's should be made with great care, and of hard material, and their motion should be smooth and steady.

The telescope should be strongly supported and well balanced, so as to rest at any inclination, and to be easily turned about the pivots. The wires in the focus should be seen sharply and distinctly defined when the telescope is pointed towards the edge of a tolerably bright distant object by daylight. Sometimes, owing to bad workmanship in the object-glass or eye-piece, and to the eye-hole being too large and too near the eye-glass, the wires appear to be doubled or trebled, and very indistinct, and no adjustment of the focus will make them appear sharp and single. This defect arises from Interference or Diffraction, and may sometimes be remedied by diminishing the eye-hole, which need not be larger than the pupil of the eye, and ought to be exactly in its proper place.

The wires should move perpendicularly across the tube of the telescope when the screw which moves them is turned. If they continue to appear well defined when the screw is turned, their motion is correct.

403 *Examination of the Pivots.*—If the pivots are imperfect in any way, the instrument is good for very little. To test the pivots, place the level on them in the manner represented in fig. 127 (*bis*), and turn the telescope slowly and carefully round, watching the bubble all the time; then, if the bubble keeps steadily in the same position, we may be sure that the pivots are truly cylindrical, and have the same imaginary axis; at least, if there be any inequality in the shape of one pivot, there must be precisely the same in the other, and the two errors destroy each other. Of course the pivots ought to be cylindrical, and they may always be so made; but corresponding and exactly equal deviations from the cylindrical form in each pivot would not

Fig. 127



affect the performance of the transit instrument. That such equal imperfections should exist is, of course, a scarcely possible accident, and therefore we may conclude that, if the bubble does not move as the telescope is turned slowly round, the pivots must be cylindrical and *conaxial*, if we may use the word in imitation of 'concentric.'

404 But it is necessary also that the pivots should be of exactly the same size; the reason why will appear when we come to speak of the adjustments of the instrument. To examine this point, place the level as before, the leg C on the pivot P, and D upon Q, (see fig. 127, *bis*,) and note the position of the bubble; then raise the level off the pivots, and, taking up the telescope, carefully reverse the pivots, that is, place the pivot P on the Y upon which the pivot Q rested before, and Q on the Y upon which P rested before; P will then be on the side M, and Q on the side N. Having done this, put the level again on the pivots in the same position as before; that is, the leg C on the side N, and D on the side M, so that now the leg C will rest on the pivot Q, and D on P. Then note the position of the bubble, and if it remains exactly where it was before, and continues in that position when the telescope is turned slowly round, we may be sure that the pivots are of exactly equal size.

405 It might be easier to test the equality of the pivots otherwise, but the method just described is that most suitable with reference to the use of the equality of the pivots. In fact, it is necessary often to reverse the pivots, and it is on this account that their equality is a matter of importance; otherwise they might differ in size without causing any error in the performance of the instrument.

406 Hence the goodness of the pivots is completely tested by the following methods of examination, viz.:—

1. Place the level on the pivots, turn the telescope slowly round, and watch the bubble.

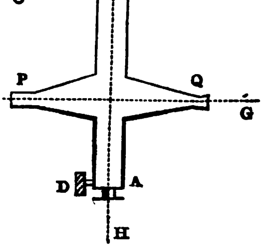
2. Reverse the pivots (but not the level) and note the bubble again as the telescope is turned slowly round.

If in both cases the bubble remains unmoved, and in exactly the same place after the reversion of the pivots as before, then we may place perfect reliance on the accuracy and equality of the pivots.

III. *Adjustments of the Transit Instrument.*

407 We have not space to say more respecting the examination of the transit instrument than what has been just stated. It is highly important for an observer to be able to examine an instrument, and determine whether it has any imperfections or errors which ought not to exist, and which he has neither the skill nor the means to correct. Such errors are those just alluded to, which it is the part of opticians and not the observer to correct, and which completely spoil the performance of the instrument. But there are other errors, which the observer and not the optician must get rid of, and which require repeated correction. These are usually called the *Adjustments* of the transit instrument.

Fig.130



408 *Adjustment of the Line of Collimation.*—In fig. 130 (*bis*), A B is the telescope, P and Q the pivots, and F G the imaginary axis of the pivots; then, the pivots being supposed to be perfectly cylindrical and conaxial, it is manifest that the line F G remains unmoved when the telescope is turned about the pivots. Now H K, the line of collimation, ought to be

perpendicular to this line, in order that it may move accurately in the same plane; for, if it be not at right angles to H K, it will describe a conical and not a plane surface. It is necessary, therefore, to adjust the line of collimation so that it may be perpendicular to the imaginary axis F G about which it turns.

To do this we must remember that by turning the screw D, we move one extremity of the line of collimation; for the line of collimation is that line which is drawn from the point of intersection of the cross wires through the centre of the object-glass, and by turning the screw D we may move the cross wires either to the right or to the left at pleasure, and so place them in any required position. Hence we only require a method or test for determining whether H K is perpendicular to F G or not. The following simple method is the most accurate that can be employed:—

409 *Reversion a test of Perpendicularity.* — Suppose P Q and A C, fig. 131, to be two rods fixed together, not quite at right angles to each other, the extremity A of the rod A C being a little on the right of the true perpendicular R S. Let us now reverse the extremities P and Q—that is, let us take up the rods and turn them over, so as to place P where Q was before, and Q where P was before; which, being done, it is clear that the rod A C will now lie in the position A′ C′, the extremity A′ being as much to the left of the true perpendicular R S as A was to the right of it. Thus P Q, A C represent the rods in one position, and P′ Q′ A′ C′ in the reversed position, the line R S, which is perpendicular to P Q, being exactly half-way between A C and A′ C′.

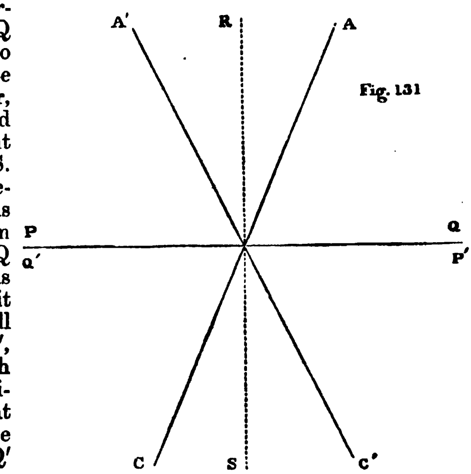


Fig. 131

Hence this reversion is a test by which we can determine practically whether A C is perpendicular to P Q or not. If A C is not perpendicular to P Q, as above supposed, the reversion of P and Q will cause the rod A C to lie in a different position to that in which it lay before; that is, after the reversion the extremity A of A C will fall as much to the left of the true perpendicular as it was to the right before, or *vice versa.* But if A C is perpendicular to P Q, then the reversion will produce no change in the position of A C.

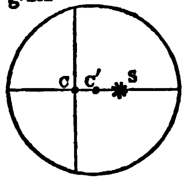
410 To apply this to the transit instrument, we have only to suppose P Q to be the imaginary axis of the pivots, and A C the line of collimation; then, if we take up the telescope and put it down again, reversing the pivots, we shall not alter the position of the line P Q, because the pivots are of exactly equal size, (and here the importance of the equality of the pivots is manifest;) in other words, after the reversion the imaginary axis of the pivots will lie exactly in the same line as before. Hence, if the line of collimation points in exactly the same direction after the reversion as before, it must be at right angles to the imaginary axis; but if this is not the case, the two lines are not perpendicular to each other.

411 Hence we derive the following method of adjusting the line of collimation so as to make it perpendicular to the imaginary axis about which it turns.

Point the telescope to some distant object, say a star, and suppose that the star is seen at the centre of the cross wires: take up the instrument off the

Y's, and put it down again carefully, with the pivots reversed, and point it at the star again; then, if the star appears again at the centre of the cross wires, the line of collimation is perpendicular to the axis; but if the star is seen either on the right or left of the centre of the wires, the line of collimation is not perpendicular to the axis.

Fig. 132



To adjust the line of collimation, let C, fig. 132, be the centre of the wires, and S the star, seen, after the reversion, to the right of C; then, by turning the screw D, (fig. 130, *bis*,) move the centre of the cross wires to the right until it comes to the point C', which is half-way between C and S. This being done, the line of collimation becomes perpendicular to the axis. The reason why we move the centre of the cross wires half-way towards the star, is because the point S, which marks where C was before the reversion, falls as much to the right of the true perpendicular as C, after the reversion, does to the left.

412 If the screw D has a graduated head, we may move C half-way towards S with accuracy; but if not, the eye must judge as well as it can the half-way point C'. To test whether the centre of the cross wires has been moved into the proper position exactly, reverse the pivots again, and if no change takes place in the position of the star, the position of the wires is correct. Otherwise the adjustment must be made again. A few trials will answer to make the adjustment of the line of collimation complete.

In each case, before the reversion, the star should be brought to the centre of the wires; this is easily done by turning the telescope till the star comes on the horizontal wire, and then turning the screw of the horizontal Y, until the star (which will appear to move along the horizontal wire as the screw of the Y is turned) comes to the centre of the wires.

The star made use of for this adjustment should be the pole star; the apparent diurnal motion of any other star, while the pivots are being reversed, would give rise to some error, but the motion of the pole star is too slow to be perceptible in so short a time. A distant mark on some building is what is generally employed for this adjustment in large fixed instruments; but it may not be easy for a traveller to find such a mark when required, inasmuch as it must be a well-defined point at a considerable distance from the observer.

413 *Adjustment of the Axis of the Transit Instrument by the Level.*— The next thing to be done is to make the imaginary axis of the pivots perfectly horizontal by means of the level, so that the plane in which the line of collimation moves may be a vertical plane.

Before making this adjustment, the instrument should be placed, as nearly as it is possible to judge, in its proper position, either in the meridian or in the prime vertical, as the occasion may require. To place the instrument nearly in the meridian, point the telescope towards the Pole star, or rather about a degree and a half on one side of the Pole star, towards the middle of the Septemtriones, at the same time keeping the bubble as near the middle of the level as possible. If this be done, the instrument will not be much out of the meridian; at least it will be sufficiently near the meridian plane to enable the observer to place it accurately in that plane by a further adjustment, which we shall soon explain.

414 Another point to be attended to before making the adjustment of the axis with the level, is to examine the motion of the horizontal Y when its screw is turned, in order to secure the perfect horizontality of that motion. If this be not done before adjusting the axis, then any motion of the horizontal Y which may be afterwards necessary, will derange the adjustment of the axis. To make the motion of the horizontal Y perfectly horizontal, we must give its screw a few turns, and note the effect produced on the bubble of the level. If the bubble remains stationary, we may be sure the horizontal Y

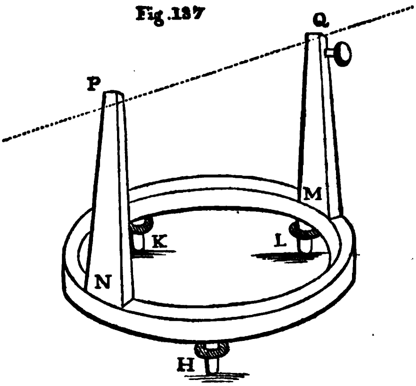
moves truly horizontally; but if the bubble moves, this is not the case. If the motion of the Y is not found correct in this way, we have only to turn one of the foot screws or short legs on which the stand is supported, until the bubble ceases to move, when the screw of the horizontal Y is turned.

415 These points being attended to, we may proceed to adjust the axis by the level as follows:—

Place the level with its legs C and D resting upon the pivots P and Q, and note the place of the bubble; afterwards take up the level, reverse it, and put it down again, so that C may rest on Q, and P on D, and note the place of the bubble again. Then, if the bubble has not altered its position, we may be sure that the imaginary axis of the pivots is perfectly horizontal; but if the bubble has moved, turn the screw of the vertical Y till the bubble moves half way towards its original position. It will then be found, on reversing the level again, that the bubble does not move, and therefore that the axis is horizontal. If, however, the bubble should move a little after the second reversion, (which may happen if the adjustment is not carefully made,) it will be necessary to move the bubble, by turning the screw of the vertical Y half way towards its position after the first reversion. A few trials will soon make the axis quite horizontal, which will be made manifest by the position of the bubble not being affected by the reversion of the level.

416 We have here described the adjustment of level, as being made by moving the vertical Y. In most portable instruments, however, the vertical Y is immovable, and the adjustment of the axis is made by turning the foot screw or short leg which is under the horizontal Y. The stand on which the two pillars are supported is often circular, as is shown in fig. 137, where N P M Q are the two pillars; P Q the axis of the pivots, the horizontal Y being at Q; H, K, L the three foot screws, one of which, L, is immediately under Q, and the other two, K and H, equidistant from L. By turning L, it is evident we raise or depress Q, and so we may make the line P Q horizontal. The previous adjustment, above described, by which the motion of the horizontal Y is made truly horizontal, is effected by turning either of the screws H or K. The subsequent turning of L will not derange this adjustment, if H and K be equidistant from L, and N exactly opposite M.

Fig. 137



417 *Adjustment of the Vertical Wire.*—It is important that the vertical wire in the focus of the telescope should be truly vertical, for then it will show, through its whole length, the vertical plane in which the centre of the wires moves when the telescope is turned about its pivots, or rather, the vertical plane described by the line of collimation: so that, if a star be seen on any part of the vertical wire, we may be sure that it is in the plane described by the line of collimation, without having to turn the telescope, so as to bring the star exactly to the centre of the cross wires. This will often save trouble; and indeed it is essential in nice observations not to be obliged always to bring the centre of the cross wires to bear upon any star we may be observing, but simply to allow the star to move across the field of view, and meet the vertical wire wherever it may happen to do so, whether at the centre, or above it, or below it. It is, however, better to point the telescope so that

the star may move across the central part of the field of view; for the vision is not always distinct near the extreme parts of the field of view.

To determine whether the vertical wire is truly vertical or not, we have only to bring a star upon it, and gently turn the telescope, the axis having been made truly horizontal by the previous adjustment; then if the star appears to run along the wire, the wire is truly vertical; but if the turning of the telescope makes the star appear to move off the wire, then the wire is not truly vertical.

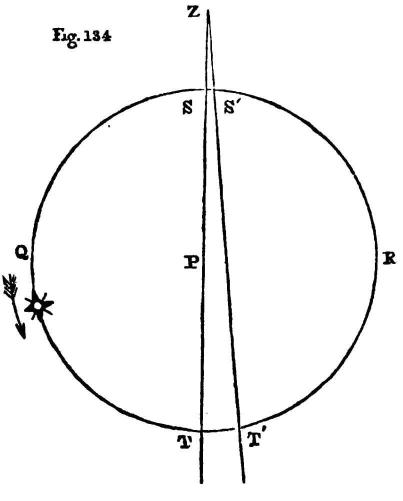
If the wire be found, on examination after this manner, to be out of the vertical, the wires must be turned round a little by means of a screw, which is generally accessible to the observer; but sometimes it is not, or there is no screw, and then this adjustment must be left to the instrument maker.

418 *Meridian Adjustment of the Transit Instrument.*—Having placed the instrument with its axis perfectly horizontal, and the telescope moving nearly in the plane of the meridian, and having made the motion of the horizontal Y truly horizontal, one more adjustment is required, in order to place the instrument exactly in the meridian—that is, so to place it, that the line of collimation may move truly in the meridian plane. This may be effected, without deranging the previous adjustment of the axis, by simply turning the screw of the horizontal Y. It remains, therefore, to explain the test by which it may be known whether the line of collimation moves in the vertical plane or not.

419 *Superior and Inferior Transits of a Circumpolar Star test the Meridian Adjustment.*—Let us consider the circumpolar motion of any particular star not far from the pole, as, for instance, *α* Ursæ Majoris. This star describes a circle about the pole in twenty-four hours, and never sets; it will therefore cross the meridian twice every twenty-four hours, once below the pole, and once above the pole. The star's transit across the meridian below the pole is called its *inferior* transit, and that above the pole its *superior* transit. The interval of time between the superior and inferior transits of every star is exactly twelve hours, sidereal time.

Hence we have an accurate test by which to determine whether the line of collimation moves in the meridian plane or not; for if it does, the interval between the two appearances of the star on the vertical wire will be exactly twelve hours sidereal time; but if it does not, the interval will be either greater or less than twelve hours. All that we have to do, therefore, is to watch *α* Ursæ Majoris, or any other circumpolar star, when it is below the pole, and note the exact time when it crosses the vertical wire; and in about twelve hours, when it will be above the pole, watch it again, and note the exact time of its coming on the vertical wire: then if the interval between the two times is exactly twelve sidereal hours, the line of collimation moves in the meridian plane; otherwise it does not.

Fig. 134



420 To explain this important point more completely, let P (fig. 134) be the pole, Z the zenith, Q S S′ R T′ T the circle which the star describes about the pole, S being the place of the superior transit, and T that of the inferior. Also suppose that the line of collimation does not move exactly in the meridian plane, and that Z S′ T′ is the portion of the great circle

it describes on the celestial sphere, which circle of course passes through the zenith Z, since the plane in which the line of collimation moves is made truly vertical by the adjustment of the axis of the transit instrument.

Now, when the star is at S′ it will be seen on the vertical wire, if the telescope be pointed towards it; and again, when it comes to T′, it will also appear on the vertical wire, the telescope, of course, being sufficiently lowered, that the star may be seen again in the field of view. The interval of time between these two appearances on the wire will be the time the star takes to move over the space S′ S Q T T′. Now the time the star takes to describe the space S Q T is twelve hours exactly; therefore the interval between the two appearances of the star on the vertical wire will be a little greater than twelve hours, the excess being the time the star takes to move from S′ to S, together with that from T to T′.

Hence it is manifest that if the line of collimation move eastward of the pole, as is represented in the figure, the time reckoned from the superior to the inferior transit across the vertical wire will exceed twelve hours; and *vice versa*, if the line of collimation move westward of the meridian, the same interval of time will fall short of twelve hours.

421 To find out the angle of deviation S Z S′ of the plane in which the line of collimation moves, mathematicians give a formula by which it can be computed from the observed interval between the two transits across the vertical wire; but this formula requires both the latitude of the place and the declination of the star to be known. We shall give here a different method, which has the advantage of being easily understood, and requires neither the latitude nor the declination of the star to be known.

To apply this method it is necessary that the screw of the horizontal Y should be very accurately made, in fact, that it should be a fine micrometer screw, and have a graduated head, such as we have already described. There would be practical difficulties in making a screw of this kind work correctly; but a micrometer screw, to move the wires of the focus, which is often added to transit instruments, would answer the same purpose. It is easier, in explanation, to consider that the Y is moved.

IV. *Method of finding the True Time of Transit of a Star across the Meridian with a Transit Instrument not exactly in the Meridian Plane.*

422 *Of the Clock, or Chronometer.*—We must say a word respecting the instrument for measuring time, which must always accompany the transit instrument. When the observer never has to move from place to place, the clock will be the proper instrument to use for measuring time; otherwise, as a clock is not portable, he must employ a chronometer, which is a large watch of peculiar and very accurate construction. The chief thing to be noticed respecting the chronometer is, that it has a peculiar scapement, which gives a distinctly audible and sharp tick. It is by listening to this tick that the observer counts time; for he cannot look at the hand of the chronometer at the same time that he is looking through the telescope, and therefore he must use his ear for observing time. The seconds hand of the chronometer is the large hand, and not the minute hand, as in a common watch. The seconds hand does not move like that of a watch, but drops from one second mark to another on the dial plate in a remarkably steady and regular manner, making a sharp tick each time. The chronometer, we shall suppose, is regulated exactly to sidereal time.

423 *To determine the effect of turning the Screw of the Horizontal Y.*—Suppose the telescope to be pointed at any particular star, S, fig. 134 (*bis*), and that by turning the screw of the horizontal Y the vertical wire A B is made to *bisect* the star, that is, to pass exactly through the centre of the image of the star, so that half that image may appear on one side of the wire, and

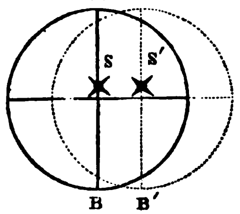


Fig. 134

half on the other. Then, in consequence of the diurnal motion of the heavens, the star will move, but by turning the screw of the horizontal Y, we may make the vertical wire always to follow the star, so that, when the star has moved to S′, the vertical wire shall move to the position A′ B′, and still bisect the star. It will require some practice to be able to turn the screws so as to keep the wire always bisecting the star; also the screw must be accurately made, and the motion easy and smooth: but very soon an observer will acquire the power of doing this with the greatest ease, in fact quite mechanically and habitually.

Now this being the case, listen attentively to the ticking of the chronometer, keeping the vertical wire upon the star by turning the screw of the Y, and just at a tick cease turning the screw and let the star move off the wire; then look at the graduated head of the screw, and note the graduation shown by its index. Having done this, look again at the star, which of course will now have moved some way from the wire, and turn the screw till the wire comes up to the star; then, just at a tick, cease turning the screw, look at the graduated head, and note the graduation shown by the index.

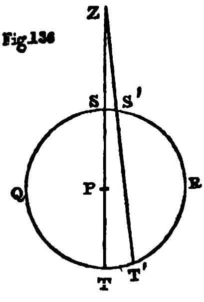
During these operations the ticks of the chronometer must be carefully counted, so as to observe by the ear the number of seconds that elapse between the two ticks at which the motion of the screw was stopped.

424 Now suppose that A B, fig. 134 (*bis*), is the place of the vertical wire at the instant (or tick) when the motion of the screw ceases the first time, and A′ B′ its place the second time; and suppose also that the number of seconds counted while the star was moving from S to S′ is ten, and that the number of turns of the screw of the Y which produced that motion is two, then it is evident that since two turns of the screw correspond to ten seconds of time, one turn corresponds to five seconds; that is, one turn of the screw moves the wire over a space which the star takes five seconds to describe, so that if the star be on the wire at any instant, and one forward turn be given to the screw of the Y, it will be five seconds before the star comes on the wire again.

In general, divide the number of seconds counted by the corresponding number of turns of the screw, and that will give the number of seconds corresponding to one turn of the screw, and so determine the effect of turning the screw.

425 It will be found that the number of seconds corresponding to one turn of the screw of the Y will be greater at the inferior than at the superior transit. The reason of this is manifest from fig. 136; for, supposing that one turn of the screw moves the circle of collimation* from Z T to Z T′, T T′ is greater than S S′, and therefore it will take a longer time for the star to perform the former distance.

Fig. 136



426 *To find the exact Time of Transit across the Vertical Wire in any position.*—Let Z S P T, fig. 136, be the meridian, Z the zenith, P the pole, S′ S Q T T′ R the circumpolar course of the star, Z S′ T′ the vertical circle described by the line of collimation, which is not supposed to move exactly in the meridian.

A little before the star comes to S′, that is, a little

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* That is, the circle which the line of collimation describes on the celestial sphere as the telescope is turned about its axis.

before it comes on the vertical wire at its superior transit, look at the chronometer, and note the hour, minute, and second; note also the graduation of the screw of the Y, shewn by its index. Then, counting the seconds or ticks carefully, watch the star, and by turning the screw, bring the wire upon the star just at a tick of the chronometer; note the graduation of the screw, (as described in Art. 424,) bring the wire again on the star, and again note the graduation of the screw, counting the ticks all the time. Suppose the results of these observations to be as follows:—

(1) Graduation of screw before it is moved 0
(2) When the wire is brought upon the star the first time . . . { Time noted . . . . . . $1^h\ 2^m\ 3^s$
Graduation of screw shows $1\frac{1}{4}$ turns.
(3) Ditto, ditto, the second time . { Time noted . . . . . . $1^h\ 2^m\ 7^s$
Graduation of screw shows $3\frac{1}{4}$ turns.

Then from (2) and (3) it follows, as we have explained in Article 424, that one turn of the screw corresponds to 2^s: therefore, if we suppose $3\frac{1}{4}$ turns to be given to the screw backwards, which will put the line of collimation where it was orignally (that is, at S′), this will correspond to $6\frac{1}{2}^s$; in other words, the star was at S′ $6\frac{1}{2}^s$ before the time (3), and therefore the exact time of the star's crossing the vertical wire in its original position was $1^h\ 2^m\ \frac{1}{2}^s$.

In this manner the exact time of a star's crossing the vertical wire, in whatever position it is placed, may be easily found. The rule in general is as follows:—

Supposing the graduation of the screw originally to be 0 (any other number will do as well), subtract the time (3) from the time (2), and the number of turns (3) from the number of turns (2), divide the former difference by the latter, multiply the quotient by the number of turns (3), and subtract the result from the time (3): then the time so obtained will be the exact time when the star crossed the vertical wire in its original position (1).

427 The above method, or something equivalent, is absolutely necessary for accuracy, because it may happen, and generally happens, that the star crosses the wire between two ticks. Astronomers always guess the instant, or fraction of a second, between the two ticks, when the star is on the wire, and to attain greater accuracy they have three, five, or seven wires in the focus, equidistant from each other (see fig. 127). They judge, as well as they can, how far the star is from each wire at the tick just before it crosses it, so determine the time of transit across each wire, and, by taking an average, the time of transit across the middle wire.

428 *To find the exact Time of a Star's Transit across the Meridian.*—Referring to the same figure and letters as in Art. 426, and supposing everything the same as in that article, find the exact time of the star's being at S′, by the method just explained: find also, in the same way, the exact time of the star's being at T′, by making the observations at the inferior transit, and suppose that one turn of the screw corresponds to 2^s at S′, and to 3^s at T′. Furthermore, let the time of the star being at S′ be $1^h\ 2^m\ \frac{1}{2}^s$, and the time of its being at T′, $13^h\ 2^m\ 10\frac{1}{2}^s$. Then it follows, that the time the star takes to move from S′ to T′ is $12^h\ 0^m\ 10^s$, and therefore, since the time from S to T is 12^h exactly, the two times, from S′ to S and from T to T′, must together be 10^s. But since one turn of the screw of the horizontal Y at S′ corresponds to 2^s, and at T′ to 3^s, the spaces S S′ and T T′ must be in the proportion of two to three, and therefore the whole time of describing these spaces being 10^s, it follows, that S S′ is described in 4^s, and T T′ is 6^s. Now the time of the star's being at S′ is $1^h\ 2^m\ \frac{1}{2}^s$; therefore the star will be at S in 6^s more, that is, at the time $1^h\ 2^m\ 6\frac{1}{2}^s$. It appears therefore that the exact time of the star's crossing the meridian at S is $1^h\ 2^m\ 6\frac{1}{2}^s$.

429 In general, to find the time of the star's being at S, we must find the times of its being at S′ and T′, by the method above explained, and thence the time it takes to move from S′ to T′. The excess of this time over 12^h

is the time the star takes to describe the two spaces S′ S and T T′, and these two spaces are described in times proportional respectively to the times corresponding to one turn of the screw at S′ and T′. Hence, if we assume t to represent the excess over 12^h of the time of moving from S′ to T′, and a and b to represent respectively the times corresponding to one turn of the screw at S′ and T′, we have the following proportion—

$a+b : t :: a :$ the time of moving from S′ to S.

From this proportion the time of moving from S′ to S being found, and being added to the time of the star's being at S′, the result will give the exact time of the star's crossing the meridian at S.

V. *Method of observing Transits across the Prime Vertical.*

430 One of the best methods of finding the latitude of a place consists in observing the transit of a known star across the Prime Vertical; we shall therefore explain how such a transit may be observed.

431 *Method of placing the Transit Instrument nearly in the Prime Vertical Plane.*—First place the instrument as nearly as can be judged in the meridian plane, in the manner already explained, and fix a common magnetic needle or mariner's compass on some convenient part of the stand, so that the needle may move freely in a horizontal plane.[*] Furthermore suppose, for the sake of simpler explanation, that the needle is made to point to the North point of the compass. Having done this, lift up the whole instrument and turn it round till the needle points to the East or West point of the compass, and put it down again carefully, so that the needle may continue to point in either of these directions. The instrument will then be placed nearly in the prime vertical plane.

For it is obvious that the plane of collimation is now at right angles to its original position, in which it was nearly coincident with the meridian plane, and therefore, since the prime vertical is perpendicular to the meridian, the plane of collimation is now nearly coincident with the prime vertical plane.

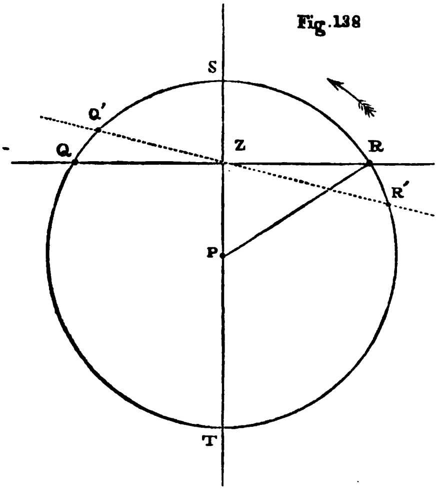
Fig. 138

432 When the instrument has been thus placed, the level should be applied, in the manner already explained, in order to make the axis perfectly horizontal. When this is done, the line of collimation will describe a vertical plane nearly coincident with the prime vertical.

433 *To determine, by means of the instrument thus placed, the exact time of Transit of a Star across the Prime Vertical.*—Let P, fig. 138, be the Pole, Z the Zenith, S Z P T the Meridian, Q Z R the Prime Vertical, which is at right angles to the Meridian, and Q′ Z R′ the circle of collimation—that is, the circle which the line of collimation describes on the celestial sphere. Observe the lines S T Q R and Q′ R′ represent circles of the sphere which appear to be projected as straight lines on a horizontal plane to an eye looking vertically upwards on the sphere.

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[*] It will be advisable, in purchasing a transit instrument, to order a magnetic compass to be fitted to it on some convenient part of the stand.

The circle of collimation Q′ Z R′ is supposed to deviate a little from the prime vertical Q Z R, but the amount of deviation is unknown. We can observe, in the manner already explained, the exact time when the star crosses the circle of collimation, that is, supposing S Q T R to represent the circular course of the star round the Pole, we can observe the exact times of the star's being at R′ and Q′. We suppose the star to cross the prime vertical twice, (which it will do, if it crosses the meridian beyond the zenith at its superior transit S,) once on the east of the meridian, and once on the west.

434 We must observe, before proceeding, that the time of the star's transit across the meridian at Q′, is supposed to be known, either by actual observation (as above explained), or from the star's known right ascension. If it be the same star as that by which we have determined the meridian (as above explained), of course its time of transit at S is known by observation; if not, the right ascensions of both stars must be found from the Ephemeris, or Nautical Almanack, and the difference taken, and this will determine the time that elapses between the transits of the two stars, and therefore the time of transit now required.

For example, suppose that the superior transit of the star (call it α) by which the meridian was determined was observed to take place at $1^h\ 4^m\ 10^s$, and that the right ascension of another star (call it β) exceeds that of α by $4^h\ 2^m\ 3^s$; then β will cross the meridian $4^h\ 2^m\ 3^s$ after α, and therefore the time of transit of β will be the sum of—

$$\begin{array}{rrrr} & 1^h & 4^m & 10^s \\ \text{and} & 4^h & 2^m & 3^s \\ \hline \text{that is,} & 5^h & 6^m & 13^s \end{array}$$

CHAPTER VIII.

THE GEOGRAPHICAL USES OF THE TRANSIT INSTRUMENT.

HAVING explained fully the construction of, and method of observing with the Transit Instrument, it will not require many pages to show how it may be used for geographical purposes.

The chief things which a traveller has to determine at any place, by means of astronomical observations, are as follows:—

The Position of the Meridian.
The Latitude.
The Longitude.

We shall now explain, in order, how these three things are to be determined.

I. *Determination of the Position of the Meridian.*

438 To determine the meridian, we have only to determine, by the method explained in the preceding chapter, the exact time when any particular star crosses the meridian; and, knowing this, we may, by turning the screw of the horizontal Y, bring the line of collimation into the meridian plane, with great accuracy, as an example will best show:—

Suppose that any particular star is observed to cross the wire at the time $6^h\ 12^m\ 17^s$, and that it is calculated, by the method explained in the previous chapter, that the star crosses the meridian exactly at the time $6^h\ 12^m\ 23^s$; also, suppose that one turn of the screw corresponds to 3^s. Then it follows, that the star takes 6^s to move from the wire to the meridian, and, consequently, that two turns of the screw will bring the wire up to the meridian. We have only, therefore, to give the screw two turns, and we shall so bring the line of collimation exactly into the meridian plane. Since the star crosses the meridian after the wire, the screw must be turned so as to make the wire move the same way that the star does—that is, westward at a superior transit, and eastward at an inferior.

In general, to bring the line of collimation exactly into the meridian plane, we must divide the time the star takes to move from the wire to the meridian, by the time corresponding to one turn of the screw, and the result will show how much we must turn the screw in order to bring the wire into the meridian.

439 Having thus ascertained the precise position of the meridian, some mark, as distant as possible, is generally chosen to indicate either the north or the south point of the horizon. This mark is called the *Meridian Mark.* Its use is—to enable the observer to place his transit instrument in the meridian plane on any future occasion, without having to make fresh astronomical observations; it also serves to determine whether the instrument has been in any way displaced or disturbed, by accident or otherwise.

This mark should be, if possible, some small, well-defined object, such, for instance, as the point of a church spire, or the top of a pole fixed in the ground; or it may be the vertical edge or extremity of some object, such as a chimney or house. It is not possible, of course, to get a mark of this kind exactly in the meridian, nor is it necessary to do so; it will be sufficient if the mark is near the meridian,—that is, within a few turns of the screw, or, to speak more definitely, so near, that a few turns of the horizontal screw may be sufficient to make the vertical wire move from the mark to the meridian. Of course the exact number of turns of the screw, by which the wire is moved from the mark to the meridian, must be noted, in order that we may be able to place the instrument in the meridian, which is done by first making the wire coincide with the mark, and then giving the screw the proper number of turns to bring the wire into the meridian. If the mark be a small round or narrow vertical object, the wire may be considered to coincide with it when it appears to be bisected by the wire.

440 It is important for several reasons not to trust entirely to a meridian mark, and therefore observations should always be made to determine whether the instrument is exactly in the plane of the meridian or not. The use of a meridian mark, geographically, is to define the north or south points of the compass in any particular locality.

II. *Determination of the Latitude.*

441 A very exact and simple method of finding the latitude of any place by observation is by means of transits across the prime vertical, as proposed by Bessel, and adopted with great success in the Russian surveys. We have already shown how the transit instrument is to be placed in the prime vertical, and it is only necessary to explain the method of finding the latitude by the use of the transit instrument thus placed. The great advantage of this method is, that it requires no corrections for refraction and parallax, which are sources of error in other methods of finding the latitude.

442 *Method of finding the Latitude of a place by observing Transits across the Prime Vertical.*—Let P, fig. 138, represent the Pole; S Q′ Q T R′ R the circumpolar circle, which any star describes in twenty-four hours; Z the zenith; S Z P T a portion of the meridian; Q Z R a portion of the prime vertical, which is, it will be remembered, at right angles to the meridian.

Let the transit instrument be placed as nearly as possible in the prime vertical, that is, let it be placed in such a manner that the line of collimation of the telescope may describe a plane very nearly coincident with the prime vertical plane. This may be done by means of a magnetic compass fixed on the stand of the instrument. The instrument is first to be placed as nearly as possible in the meridian, as above explained, and then the whole is to be lifted up, turned round till the magnetic needle moves through 90°, and then set down again.

443 Sometimes the instrument has an azimuthal motion, that is, it is capable of being turned round a vertical pillar or axis; and it has a graduated horizontal circle. In this case, after having placed the instrument as nearly as possible in the meridian, we have only to turn it round the vertical axis through 90°, by means of the graduated horizontal circle; and, this being done, the instrument is placed nearly in the prime vertical.

444 When the instrument is thus placed, the axis of the telescope must be carefully levelled, as above explained, otherwise the observations made will be erroneous. It is very important, in all observations with the transit instrument, to attend particularly to the horizontal adjustment of the axis of the telescope.

445 Supposing, then, that the instrument is placed as nearly as possible in the prime vertical, let R′ Z Q′ represent a portion of the vertical circle, which the line of collimation describes on the celestial sphere when the telescope is turned round its axis. This circle passes through the zenith Z, because, the axis being properly levelled, the line of collimation describes a vertical plane; also, this circle, as we have supposed, is nearly coincident with the prime vertical Q Z R.

Now, the star which is supposed to describe the circle S Q T R will be seen crossing the vertical wire when it arrives at R′, and afterwards at Q′. In the former case the telescope is pointing eastward, in the latter westward. Let the exact time of the star's being at R′ be observed, according to the method already explained with reference to transits across the meridian;

also, let the exact time of the star's arriving at Q′ be observed in the same manner. Furthermore, the exact times when the star crosses the meridian, at its superior and inferior transits at S and T, must be determined by observation, or by calculation, as we have explained. Then the exact time of the star's crossing the prime vertical at R or Q may be immediately determined, as an example will best show.

446 *Example.*—Let the observed times when the star arrives at T R′ S and Q′ be as follows:—

At T . . . . . $1^h\ 10^m\ 3^s$
At R′ . . . . $10^h\ 3^m\ 2^s$
At S . . . . . $13^h\ 10^m\ 3^s$
At Q′ . . . . . $16^h\ 17^m\ 0^s$

Then the interval of time from the star's being at R′ to its being at S is—

$$3^h\ 7^m\ 1^s$$

and the interval from S to Q′, is—

$$3^h\ 6^m\ 57^s$$

Now, the time the star takes to move from R′ to R may be considered as equal to that from Q′ to Q; for, inasmuch as the circles R Q and R′ Q′ are very nearly coincident, the spaces R′ R and Q′ Q differ only insensibly from each other. Therefore, since the interval from R to S is the same as the interval from S to Q, S being evidently mid-way between R and Q, it follows that the interval from R′ to R, and that from Q′ to Q, must be each 2^s, and the interval from R to S, and that from S to Q, must be each—

$$3^h\ 6^m\ 59^s$$

for then the intervals from R′ to S and from S to Q′ will be respectively—

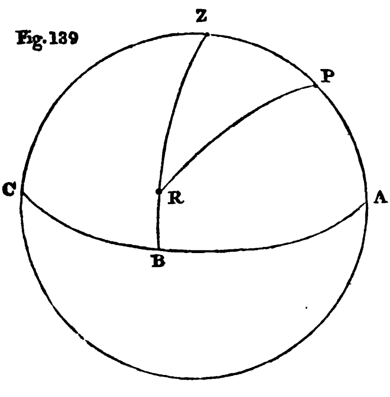
$$3^h\ 7^m\ 1^s \text{ and } 3^h\ 6^m\ 57^s$$

as they ought to be.

447 In general, the interval of time the star occupies in moving from R to S will be half the sum of the two intervals from R′ to S and from S to Q′; for it is manifest that the interval from R′ to S exceeds, and that from S to Q′ falls short of, the interval from R to S, by the same quantity, so that twice the latter interval will be equal to the sum of the two former intervals.

448 Thus the time the star takes to move from R to S may be easily determined by observation; and this also determines the angle Z P R (P R representing a portion of the polar circle, or circle of declination, drawn from the pole to the star), for, as the time of the star's moving from R to S is to 24^h, so is the angle Z P R to 360°.

Fig. 139



Thus, in the case of the example just given—

$$24^h : 3^h\ 6^m\ 59^s :: 360° : \text{angle } ZPR,$$

when the angle Z P R may be determined by the Rule of Three.

449 We are now prepared to show how the latitude may be found. Let A P Z C (fig. 139) represent the meridian; Z R B a portion of the prime vertical; Z the zenith; R the star crossing the prime vertical in the triangle Z P R in the present figure, the same as the triangle Z P R in fig. 138, only

represented in a different projection or view. Then Z P R is a spherical triangle in which we know three things; namely, the side P R, the angle Z P R, and the angle P Z R. The side P R is known, because the star R is supposed some known star, whose distance from the pole P is given in the Ephemeris, or Nautical Almanack. The angle Z P R is determined, as above explained, and the angle P Z R is a right angle, because the prime vertical Z R is perpendicular to the meridian Z P.

Hence, three things being known in the spherical triangle Z P R, we may find the remaining parts of the triangle; namely, the angle Z R P, the side Z R, and the side Z P, either by mathematical calculation, or by the method of construction we have given in a former chapter. Now Z P is the complement of the latitude, being the distance of the zenith from the pole; for the latitude is the distance of the place of observation—in degrees, minutes, and seconds—from the terrestrial equator, or, what is the same thing, the distance of the zenith from the celestial equator.

It appears, therefore, that the latitude may be found from the spherical triangle Z P R, by determining by observation the angle Z P R, as above explained.

450 The following is the construction for finding Z P. Let us take the letters l, c, Δ, h, to represent respectively the latitude, the colatitude Z P, the polar distance P R of the star, and the hour angle Z P R. Then the relation between these quantities is represented by construction in fig. 140, where the line O M is perpendicular to the line N L; N K also perpendicular to N L; and M K equal to M L. The angle N M K is h; N O M, c; L O M, Δ; and O N M, being the complement of N O M, is l. That this is the proper construction for representing the relation between c, Δ, and h, will be seen immediately by referring to the article where the construction for exhibiting the parts of a right angled spherical triangle is given.

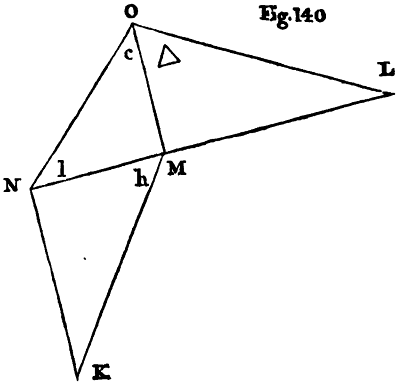


Fig. 140

Hence, to find the latitude l, Δ, and h, the polar distance and hour angle being known, as we have stated, we proceed as follows:—

Draw two lines, O L, O M, fig. 140, making the angle M O L equal to the known polar distance Δ of the star; and, taking O L of any convenient length, draw L M perpendicular to O M; draw M K equal to M L, making the angle N M K (M N being the production of the line M L) equal to the hour angle h, which has been determined from observation; then draw K N perpendicular to M N, and join N O, and measure the angle O N M, and the angle thus measured will be the latitude required.

451 We may here observe that the time of the star's transit across the meridian need not be observed, provided we know the time of transit of any other star, (as, for example, the star made use of in determining the position of the meridian,) and the right ascensions of both stars. For the difference between the two right ascensions will be the interval between the transits of the two stars across the meridian; and therefore, if the time of transit of one star is known, that of the other may be immediately determined.

III. *Determination of the Longitude.*

452 *Connexion between the Longitude of a Place and the Time.*—When it is 12 o'clock at London, it is 1 at a place 15° of longitude east of London; for, since the Sun describes the whole 360° of longitude in 24 hours, that is, at the rate of 15° per hour, he comes on the meridian of London an hour later than on the meridian of a place 15° east of London, and therefore the time at that place will be an hour in advance of that at London. In like manner, the time at a place whose longitude is 15° west of London, is one hour behind the time in London. And in general, if we consider the meridian of London to be the First Meridian, reckoning longitudes from it, the difference between the time at any place and that at London will be found by converting the longitude of the place into time at the rate of 15° per hour, the time at the place being in advance or behind that at London, according as the longitude is east or west.

453 *Method of finding the Longitude of any Place.*—Hence, in order to find the longitude of any place, we have only to determine how much the time at that place is in advance or behind the time at London, and convert the difference into degrees at the rate of 15° per hour. For example, if the time at a place be $3^h\ 6^m$ behind London time, what is the longitude of the place? To determine this, we have the proportion:

$$1^h : 3^h\ 6^m :: 15^\circ : \text{longitude required,}$$

which, by the Rule of Three, gives for the required longitude,

$$46^\circ\ 30'\ \text{west.}$$

Now, in order to determine how much the time at a place is in advance or behind the London time, we must determine two things—namely, the London time and the time at the place. How this is to be done we shall now briefly explain.

454 *Method of determining the Time at any Place.*—We have explained how time is measured by the Sun's apparent diurnal motion, corrected by the equation of time, in order to make the proper allowance for the inequalities in the Sun's motion. To determine the time at any place, that is, the mean solar time, we must determine the exact instant when the Sun crosses the meridian of that place, and make the proper correction for the equation of time, and then the time at the place will be determined.

For example, suppose that the observer has a chronometer and transit instrument, and that he obtains the following result by observation with them, and the equation of time from the Ephemeris:—

Time of the Sun's transit as shown by chronometer .	$2^h\ 4^m\ 18^s$
Equation of time, (Sun too slow)	$0^h\ 7^m\ 42^s$
Sum . . .	$2^h\ 12^m\ 0^s$

Hence the chronometer is $2^h\ 4^m\ 18^s$ faster than the time actually shown by the Sun; for it is 0 o'clock by the Sun when he is on the meridian; and the equation of time shows that the Sun is $7^m\ 42^s$ slow; therefore the chronometer is 2 hours and 12 minutes faster than the mean solar time at the place of observation, and thus that time is determined.

455 But putting back the hand of the chronometer 2 hours and 12 minutes, we may make it show the exact time of the place of observation; but this is never done, because it would spoil the chronometer to move the hand backwards or forwards as in a common watch. The error of the chronometer is noted, and this is quite sufficient; for instance, in the example just given it will be sufficient, instead of putting back the hand, to make a note that the chronometer is 2 hours 12 minutes fast at the place of observation.

456 Thus the time at any place may be determined by observing, with a

transit instrument and chronometer, the instant at which the Sun crosses the meridian. The same may be done by observing the instant when any known star crosses the meridian, and making the proper allowance for the difference of the Sun's right ascension and that of the star.

For example, suppose the star's transit to be observed, and the right ascensions of the Sun and star taken from the Ephemeris, or Nautical Almanack, as follows—

Sun's right ascension . . .	$4^h\ 12^m$	mean time.
Star's right ascension . . .	$6^h\ 16^m$	
Difference	$2^h\ 4^m$	

Therefore, when the star is on the meridian, the Sun is $2^h\ 4^m$ past the meridian; or, in other words, it is 4 minutes past 2 by the Sun.

Time of star's transit by chronometer .	$10^h\ 13^m$
Ditto by Sun	$2^h\ 4^m$
Difference	$8^h\ 11^m$
Equation of time (Sun too fast)	$0^h\ 10^m$
Sum . . .	$8^h\ 21^m$

The chronometer is $8^h\ 11^m$ faster than the time actually shown by the Sun; but the Sun is 10^m too fast; therefore the chronometer is in advance of the mean time at the place of observation by the quantity—

$8^h\ 21^m$

which, being noted, determines the mean time at the place of observation.

457 *Determination of the London Time.*—The simplest method of doing this is by means of good chronometers, set to London time, and transported with great care to the place of observation. Now, chronometers, however good, are always subject to some error in their rate of going; this error is determined as well as it can be, and is noted. Also, as we have already stated, the chronometer is not actually set to London time by moving the hand, but the error is simply noted. Thus, two kinds of error are noted, the error in London on a certain day and hour, and the gaining or losing rate of the chronometer; and, by making the proper allowance for these errors, the London time may be found from the chronometer at any place to which it has been transported.

For example, suppose the following case—

Error of chronometer in London at 12 o'clock, June 1 .	0^h	2^m	3^s	fast.
Gaining rate 1^s per day.				
Error from gaining rate at 12 o'clock, June 23 . . .	0^h	0^m	23^s	,,
Whole error at 12 o'clock, June 23	0^h	2^m	26^s	fast.

So that, according to London time, the chronometer is $2^m\ 26^s$ too fast on the 23rd of June.

458 This presumes of course on the invariability of the gaining rate of the chronometer, for this calculation supposes that the chronometer gains regularly one second per day. When chronometers of first-rate construction are transported by sea, with proper precautions against the motion of the ship, it is wonderful how little the gaining or losing rate changes. Good chronometers are therefore invaluable in navigation, for they give the London time with great facility, and therefore, as we have explained, serve to determine the longitude. The means of transport by land are by no means so favourable to the correct going of the chronometer.

459 *Method of determining London Time, by observing the Moon's motion among the fixed stars.*—The apparent diurnal motion of the heavenly bodies serves to determine the time at any particular place where the observer

actually is, but not the time at a different place, except the difference of the longitudes of the two places be known. An observer at New York may determine the time at New York by observing the daily motion of the Sun or other heavenly body; but there is nothing in the diurnal motion of the heavenly bodies which will enable him to find the time at London, except he knows how many degrees New York is west of London. It is different, however, with regard to the proper motions of the heavenly bodies among the fixed stars, for these motions are capable of showing the time at a place different from that in which the observer is stationed, without his knowing anything about difference of longitude of the two places. With the exception of the Moon, however, the proper motions of the heavenly bodies are too slow to be made use of for the purpose of determining time with any degree of accuracy: the Moon alone moves with sufficient quickness among the stars to enable us to make use of her motion with this view; and even in the case of the Moon, it requires considerable nicety on the part of the observer to attain sufficient accuracy in the results of his observations.

460 The Moon performs the circuit of the heavens among the fixed stars in less than a calendar month, and therefore describes more than 12° per day, or 30′ per hour. Suppose for a moment that she moves over 30′ per hour, and therefore 30″ per minute. Suppose also that the Moon is seen to coincide with a certain star at 0 o'clock in London, and that an observer in some other place is aware of this, but is ignorant of his longitude. Suppose that he determines the time at the place he is in, according to the method above explained, and that at 2 o'clock he observes that the Moon is 6° 10′ from the star. Now at 0 o'clock, London time, the Moon coincided with the star, but now she is 6° 10′ from the star; therefore, since she describes 12° per day, or 30′ per hour, it follows that at the time of observation it is $12^h\ 20^m$ London time—for

6° corresponds to	$12^h\ 0^m\ 0^s$
10′ „	$0^h\ 20^m\ 0^s$
Total	$12^h\ 20^m\ 0^s$

Hence the London time is determined.

We have then the following calculation for finding the longitude of the place of observation:—

Time at place of observation	$2^h\ 0^m\ 0^s$
Corresponding London time	$12^h\ 20^m\ 0^s$
Difference	$10^h\ 20^m\ 0^s$

Hence the time at the place of observation is $10^h\ 20^m$ behind the London time, and therefore

$$1^h : 10^h\ 20^m :: 15^\circ : \text{longitude of place.}$$

Whence the longitude of the place is

155° west.

461 In the foregoing example we have assumed that the motion of the Moon is perfectly uniform, in order to explain more simply the principle upon which the method of finding the London time, and thence the longitude of any place, by means of the Moon's proper motion, depends. The Moon's motion is, however, very variable, but astronomers have determined the nature and law of that variation with great exactness. They can therefore make due allowance for every inequality in the Moon's motion, and employ it to determine the longitude with the same exactness as if it was perfectly invariable.

462 *Method of finding the Longitude by Transits of the Moon.*—This method is founded upon the principle just explained, and is in fact the simplest way of applying it in practice. It consists in observing with a transit instrument and chronometer the times at which the Moon and a fixed star cross the

meridian at the place of observation, and so determining the interval of time between the two transits. The interval thus found is compared with the interval between the two transits as seen at London, which can be easily calculated from tables given in the Nautical Almanack; and the comparison immediately shows the London time at which the two transits took place when seen by the observer. The London time being thus found, of course the longitude follows, as we have explained.

For example, suppose the following case:—

Observed interval between the two transits . . .	$12^m\ 6^s$
Interval at 0 o'clock, London time, given by the Nautical Almanack	$18^m\ 6^s$
Difference	$6^m\ 0^s$

Now, suppose that we find from the Nautical Almanack that a change in the Moon's right ascension, amounting to 6^m in time, takes place in $3^h\ 4^m\ 2^s$; then it follows, that when the observer sees the Moon's transit, the London time is

$$3^h\ 4^m\ 2^s$$

Whence the longitude may be found.

463 *Lunar Method.*—The method of finding the longitude which we have just explained, is called the method of *Moon Culminating Stars,* because it consists in observing when the Moon and certain convenient stars come on the meridian, or culminate. There is another method of finding the longitude, which is usually called the *Lunar Method.* It consists in observing the distance of the Moon from some convenient fixed star, and it depends upon the principle just explained. The instrument employed in this method is one specially adapted for observing on board ship, called Hadley's sextant. A mathematical calculation is required to obtain the longitude, and the observations must be corrected for refraction and parallax. On the whole, it is much more complicated than the method of Moon culminating stars: but, since a transit instrument could not be employed on board ship, the latter method cannot be employed at sea.

CHAPTER IX.

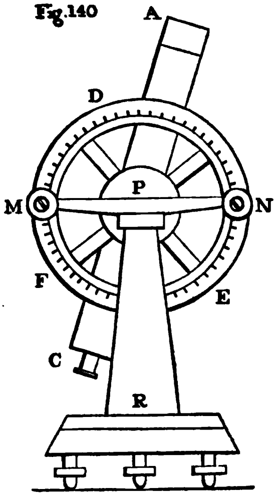
THE ALTITUDE AND AZIMUTH INSTRUMENT—HADLEY'S SEXTANT—REFRACTION AND PARALLAX.

WE have dwelt at some length on the transit instrument, because of its great practical utility, and the simplicity of its details and adjustments; besides, a knowledge of the method of using it is valuable, because other instruments are adjusted on exactly the same principles, and by similar contrivances; so that one who understands the transit instrument well, may be said to understand a good deal about astronomical instruments in general. We have now only space to say a very few words respecting two other very important astronomical instruments — namely, the *Altitude and Azimuth Instrument* and *Hadley's Sextant.*

I. *The Altitude and Azimuth Instrument.*

465 This instrument consists of a telescope C A, fig. 140, of exactly the same description as that in the transit instrument, capable of turning round a horizontal axis, the pivots of which rest on two Y's, which are fixed on two vertical pillars, one of which, P R, is represented in the figure. In fact, the

Fig. 140



telescope, axis, pivots, and pillars, are precisely the same as in the transit instrument, only the axis is generally shorter, and the pillars are closer together.

The stand to which the two pillars are fixed is a circular horizontal piece of metal, capable of moving round its centre about a vertical axis. This vertical axis is supported by another circular piece of metal, which rests on three foot screws, like the base of the transit, as we have above described it.

So far, then, the altitude and azimuth instrument is nothing more than a transit instrument, whose pillars, instead of being immoveable, are capable of moving round a vertical axis; thus the telescope has a motion about a horizontal axis, and that axis has another motion about a vertical axis. The telescope, or rather the line of collimation, moves in a vertical plane, and the axis of the telescope moves in a horizontal plane. The former is called a motion *in altitude*, because it measures the altitudes of heavenly bodies; the latter is called a motion *in azimuth*, because it measures their azimuths; and hence the name Altitude and Azimuth Instrument.

The telescope has a graduated *vertical circle*, D E F, fig. 140, attached to it, which is called the *altitude circle;* and the vertical axis, about which the pillars turn, has a graduated horizontal circle attached to it, which is called the *azimuth circle*. Both these circles are correctly centred, at least as correctly as possible, that is, the centre of the graduated circle is also the centre of motion about which the circle turns. We shall not have time to say anything here respecting the azimuth circle, but we shall confine our attention altogether to the altitude circle; in fact, we shall consider the instrument merely with reference to its use in measuring the altitudes of heavenly bodies.

466 The graduations are read off by means of two reading microscopes, M and N, fixed at opposite extremities of a piece of metal, M P N, which is attached to one of the pillars at P. We need not say much respecting microscopes, as we have already fully explained the nature and use of the microscope employed to read off the graduations of a circle. (See Articles 373—382, &c.)

In small instruments these microscopes are simply employed to magnify the graduations, which are read off by verniers, (see Articles 383, &c.,) at M and N. They are always placed exactly opposite each other; in other words, the line joining the zero point or index point of each vernier or microscope passes through the centre of the graduated circle. The object of this is to correct any error of centering that may exist in the circle; for it is easy to see that, if the centre of the graduated circle does not exactly coincide with the centre of motion, the graduations will not correctly indicate the motion of the telescope in altitude. But whatever error may be made on one side, at M, for instance, it is clear that exactly the opposite error will be made at the opposite point N: so that, if the reading at M gives the altitude, say 10″ too great, the reading at N will give the altitude 10″ too small. Suppose, then, the following case:—

True altitude	35° 20′ 17″
Altitude by reading at M	35° 20′ 7″
Ditto „ N	35° 20′ 27′
Half sum of two readings	35° 20′ 17″

Whence it appears that half the sum of the two erroneous readings at M and N is the true altitude; and this, it is easy to see, will always be the case. The use of a pair of microscopes to read off at opposite points of the graduated circle is therefore obvious, inasmuch as it is extremely difficult, in making an instrument, to avoid all error of centering.

467 In larger instruments there are often as many as three pairs of reading microscopes, in order to attain greater accuracy. All these microscopes are read off at each observation, and the mean, or average, of the whole set of readings is taken: in this way considerable accuracy is secured, for not only are the consequences of erroneous centering thus obviated, but also errors of graduation, that is, errors committed by the instrument-maker in engraving the graduations are made in a great measure to balance and destroy each other.

468 The graduations of the azimuth circle are read off in a similar manner, either by verniers or reading microscopes. Both circles may be either turned by the hand or by means of certain fine screws called *tangent screws*. A tangent screw is a screw which gives to a graduated circle a very delicate motion, and so enables the observer to make his observations with greater ease and certainty than he could otherwise do. The tangent screw may be made to act upon the graduated circle at pleasure, by means of what is called a *clamping screw*. When the clamping screw is tightened, the tangent screw acts upon the circle; but when the clamping screw is relaxed, the tangent screw produces no effect, and the circle may be turned round freely by the hand.

469 There are horizontal and vertical wires in the focus of the telescope, which, as in the transit instrument, determine the line of collimation by their intersection. These wires are moveable by means of screws, and are adjusted in their proper positions in a similar manner to that described in Chapter VII.

II. *Adjustments, and Method of Observing with the Altitude and Azimuth Instrument.*

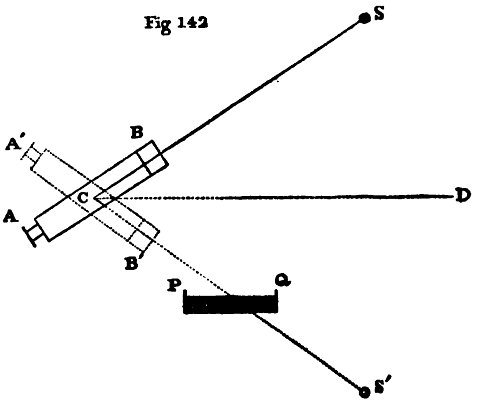
470 *Adjustments.*—Having so fully described the adjustments of the transit instrument, which are the same in kind and principle as those of the instrument we are at present considering, we must not dwell upon this subject here. The axis of the telescope must be levelled, by means of a level and the principle of inversion, as in the transit; the vertical axis about which the azimuth circle turns must be truly vertical, and both axes must be at right angles to each other. All these conditions of good adjustment are satisfied if, when a level is placed upon the pivots, and the instrument turned about its vertical axis, the bubble keeps steadily in the same position, even when the level is reversed. If no alteration is made in the position of the bubble, either by reversing the level, or turning the instrument round its vertical axis, we may be sure that the vertical axis is truly vertical, and the axis of the telescope truly horizontal.

471 *Index Error.*—This is an error affecting the verniers or reading microscopes, or the position of the telescope with reference to the graduated circle, but as it is entirely destroyed by a method of observing which we shall now explain, it will not be necessary to say anything about it.

472 *Method of observing Altitudes by Reflection.*—This method consists in observing the altitude of a star or heavenly body directly and by reflection in a trough of mercury, in the following manner:—

Let A C B, fig. 142, represent the telescope of the altitude and azimuth instrument pointing towards a star in the direction C S; let P Q be the still surface of some mercury in a trough, placed somewhat below, and in front of, the instrument; let A′ C B′ represent the position of the telescope when it is made to point towards the reflection of the star seen in the mercury, in the direction C S′; and let C D be a horizontal line.

Fig 142



Then, by the laws of reflection, the line C S′ will be as much inclined below the line C D (which is parallel to P Q, both being horizontal) as C S is inclined above C D; and therefore the angle S C S′ will be double the angle S C D. Now the angle S C D is the angle of altitude of the star above the horizon, since C D is a horizontal line. Hence, the correct altitude of the star is half the angle made by the lines C S and C S′, which are drawn respectively to the star, and to its image or reflection in the mercury.

Let us now suppose the following case, with reference to the two positions, A C B and A′ C B′ of the telescope.

Reading given by vernier in first position	29°
Ditto " " second ditto	99°
Difference	70°

This difference is evidently the angle S C S′, and therefore half this difference, 35°, is the altitude of the star.

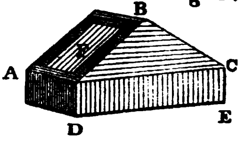
But suppose there is some error in the position of the vernier or telescope, which makes the first reading 33° instead of 29°, and of course equally affects the second reading, making it 103° instead of 99°; then the case will stand as follows:—

Reading in first position	33°
Ditto second ditto	103°
Difference	70°

And therefore altitude—35°

Hence it appears that an index error, that is, an error in the position of the vernier, or in that of the telescope on the graduated circle, does not affect the result of an observation according to this method. It is generally in this manner that altitudes are taken by means of the altitude and azimuth instrument.

Fig. 143



473 *Artificial Horizon.*—The artificial horizon is a small vessel or trough of wood, roofed in, as it were, with glass, in order to prevent the wind from disturbing the surface of the mercury. A D E C, fig. 143, is the trough for containing the mercury. A B C is the roof; F, and the opposite slanting side, which does not appear in the figure, being glass. This is a necessary instrument, when either an altitude and azimuth instrument, or a Hadley's sextant, which we shall soon describe, is used. It is made to be portable, and is rather more expensive than a purchaser generally expects, on account of the importance of having the glass roof made of accurately polished plates of glass. The mercury ought to be allowed to run into the trough through a very small hole, in order to clear the surface of the scum which will otherwise obscure it.

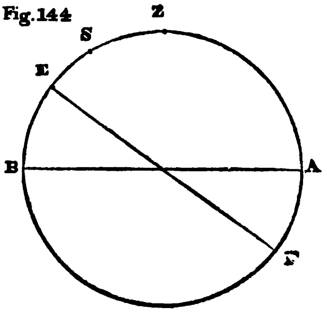
III. *Uses of the Altitude and Azimuth Instrument.*

474 We can only very briefly touch upon this part of the subject. We shall suppose the instrument to be placed in the plane of the meridian, that is, so that the line of collimation of the telescope may move in that plane; and this may be done exactly in the same manner as in the case of the transit instrument, as above explained; only the axis of the telescope is moved horizontally by means of the tangent screw of the azimuth circle instead of by moving the horizontal Y by a screw, as in the transit instrument. The instrument thus placed is equivalent to what is called the *Mural* or *Meridian Circle* in large observatories.

Altitudes of heavenly bodies observed by means of the instrument thus placed are called *Meridian Altitudes.*

475 *To determine the Latitude by observing the Meridian Altitude of a heavenly body whose declination is known.*—Let A Z E B F (fig. 144) be the Meridian, A B the Horizon, E F the Equator, S the heavenly body on the Meridian, and Z the Zenith. Then B S is the meridian altitude of the heavenly body, and this is supposed to be observed by means of the altitude and azimuth instrument. Therefore Z S, which is the complement of B S, is known. But E S is the declination of S, which is also known, and E Z is the latitude of the place. Hence, by adding Z S and E S, both of which are known, we find the latitude.

Fig. 144



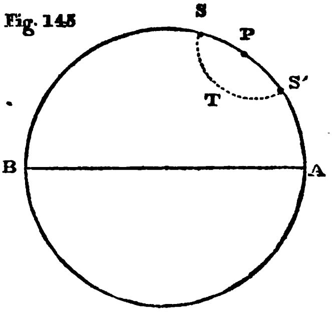
Thus, if the observed altitude be 60° 10′, and the known declination 20° 15′, we have—

	B Z . . .	90° 0′
Subtract	B S . . .	60° 10′
		29° 50′ which gives Z S.
Add	E S	20° 15′
		50° 5′

which gives E Z, or the latitude required.

476 *To determine the Latitude by observing an unknown circumpolar Star.*—Let A P B (fig. 145) be the Meridian, P the Pole, S′ T S the circumpolar circle described by the unknown star crossing the Meridian at S and S′, and A B the Horizon. Then let the meridian altitudes S A and S′ A be observed, and added together, and the sum found will give PA, the altitude of the Pole; whence the latitude, which is equal to the altitude of the Pole, is known.

Fig. 145



For example, let the observed meridian altitudes be 79° 14′ and 49° 30′; then we have—

S A	79° 14′
S′ A	49° 30′
Adding	128° 44′

Half of which is 64° 22′, which is the required latitude.

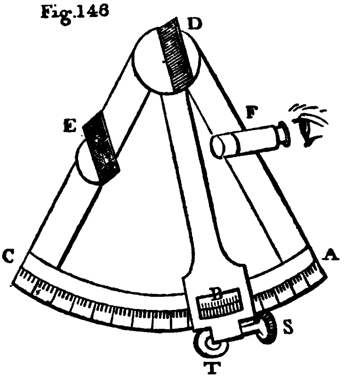
The reason why P A is half the sum of S A and S′ A is, because P is half way between S and S′, therefore S A exceeds P A by the same quantity that S′ A falls short of P A, and therefore S A and S′ A added together must just make double of P A.

477 These results must be corrected for refraction, and sometimes for other errors, as we shall briefly explain, and hence it is that these methods of finding the latitude are not by any means so simple as they appear to be.

IV. *Hadley's Sextant.*

478 This instrument is invaluable where the observer is not able to use fixed instruments, as, for instance, at sea. It consists of a stout frame D A C, fig. 146, of a triangular (or rather, sectorial) shape, of which A B C is a flat graduated circular arc, generally a sixth part of the whole circumference, (whence the name sextant,) but often it is a fourth part or quadrant. D B is an arm which moves about a centre—namely, the centre of the graduated arc A B C. The end B of this arc moves in close contact with the graduated arc, and carries an index and Vernier by which the graduations are read off. (See Article 383, &c.) S is a tangent screw, which, being turned, causes the arm D B to move very slowly; and T is a clamping screw, which, being tightened, causes the screw S to act on the arm, but, when relaxed, the arm may be moved freely by the hand.

Fig. 146



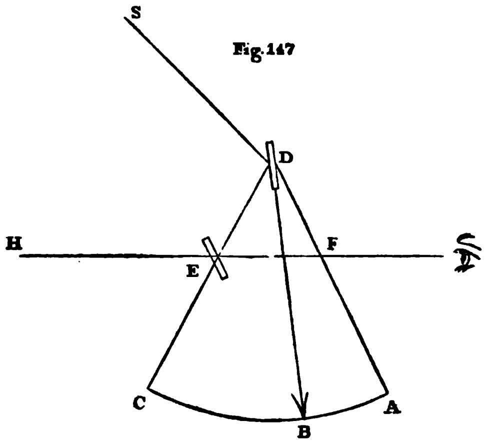
Perpendicular to the plane of the graduated arc A B C, in which plane the arm D B moves, are two mirrors E and D, one fixed at E on the side D C of the frame, and the other attached to the arm at D, immediately over the centre round which the arm turns. The mirror E is immovable, but the mirror D moves with the arm D B. Both are plane mirrors of silvered glass, but E has this peculiarity, that the upper half of the silvering is rubbed off, so that E is partly a reflector and partly transparent.

F is a telescope fixed on the side D A of the frame, and pointing directly towards the half-silvered mirror E. Behind the instrument is a handle (not shown in the figure). By this handle the instrument is held in the right hand, the left being used to move the index arm D B, or turn the screws S or T.

479 When the instrument is in proper adjustment, and the arm D B is moved till its index B is at the zero of the graduated arc A B C, which zero is near the point A, then the two mirrors D and E are so placed as to be exactly parallel to each other.

480 *Principle of Hadley's Sextant.*—Let A D C, fig. 147, represent the principal lines in fig. 146; A B C being the graduated arc, E the half-silvered mirror, D the moveable mirror on the index arm, B the index, A the zero point of the graduated arc, F the place of the telescope. Suppose S D E F to be the course of a ray of light, which, falling on the mirror D, is reflected to E, and thence again reflected towards the telescope at F, through which it passes to the eye. We may observe here, that the telescope is always so placed that the lines F E and D E make equal angles with the mirror E; and then, by the law of reflection, a ray falling on the mirror E, in the direction D E, is always reflected in the direction E F.

Furthermore, let H E be another ray of light, which, falling on the unsilvered part of the mirror E, passes straight through the telescope at F to the eye.



Then it may be proved geometrically, from the law of reflection, that the angle A D B is always half of the angle at which the two rays S D and H E are inclined to each other; so that double the number of degrees in the graduated arc A B is the angle which the ray S D makes with the ray H E. Now, the arc A B C is not graduated in the usual way, but every half degree of it is represented as a whole degree, so that there would be twice 360 degrees in the whole circumference if completed. This being the case, it is evident from what has been stated, that the number of degrees from A to B shows the angle at which S D and H E are inclined to each other. For example, if the index B points to 20°, the rays S D and H E make angles of 20° with each other.

Now, if S and H be two distant objects, two stars for instance, from which these rays come, it is clear that to the eye S will appear to be in the same place as H, for the rays of light which come from S will, by the two reflections at D and E, enter the telescope in the direction E F, in which direction the rays from H also enter the telescope. Whence it is evident, from the explanation we have given of the nature and action of the telescope, that both sets of rays will be mixed by the telescope, and enter the eye just as if they came from one object. To the eye, therefore, looking through the telescope, S will appear to coincide with H.

Hence we may state the principle of Hadley's sextant as follows:—When the telescope is directed towards a star H, and the index arm is moved till another star S is seen to coincide apparently with H; then, the number of degrees, minutes, and seconds shown by the index B on the graduated arc A C, gives the angular distance of the star S from the star H, that is, the number of degrees, minutes, and seconds between S and H on the celestial sphere.

481 *Method of observing with Hadley's Sextant.*—Suppose we wish to observe the angular distance between two stars S and H. Holding the instrument by the handle in the right hand, and the plane of the instrument (that is, the plane D A C, fig. 147,) as nearly as possible in the plane in which the two stars are situated, direct the telescope towards the lower star H, and, holding the instrument as steadily as possible, move the index arm backwards and forwards with the left hand till the other star S appears in the field of view. The moment the two stars are, as it were, thus caught in the field of view, tighten the clamping screw T, and then turn the tangent screw until the star S appears to come exactly unto the same place as H, so that both seem to be coincident with each other. When this is done, the observation is made, and the observer has only to look at the index B, which, with the help of the vernier, will show in degrees, minutes, and seconds, the angular distance between the two stars.

482 *Adjustments of Hadley's Sextant.*—We shall only mention here the adjustments which it is always necessary for the observer to attend to, which are effected by means of two screws at the back of the instrument, close under the half-silvered mirror E, and by a screw at the back of the index mirror D.

Of the two former screws, one alters the inclination of the half-silvered mirror to the plane of the instrument, that is, the plane A B C D, fig. 147; and the other alters the inclination of the half-silvered mirror to the index mirror. These two screws have milled heads generally, and may be turned by the hand. The screw at the back of the index mirror D alters the inclination of that mirror to the plane of the instrument. This screw has not a milled head, and must be turned by a screw driver, for this reason, that it ought to be meddled with as little as possible.

When the instrument is properly adjusted, both mirrors should be perpendicular to the plane of the instrument, and they should be exactly parallel to each other when the index B is at the zero of the graduated arc A C.

483 *Adjustment of the Half-Silvered Mirror.*—Bring the index B to the zero of the graduated arc, making it exactly coincident with the zero by tightening the clamping screw T, and then using the tangent screw S. Then, holding the instrument by the handle, direct the telescope towards a distant, well-defined, small object, (it must be a distant object,) say, for instance, a bright star. On looking through the telescope, the observer will see the star double if the adjustments be not perfect, one image being formed by the rays which come through the unsilvered half of the mirror E, and the other by the rays which fall on the mirror D, and are reflected by the silvered half of E to the telescope.

Let the observer now turn in succession the two screws which adjust the mirror E, and he will perceive that one of these screws makes one of the images appear to move at right angles to the plane of the instrument, and the other in that plane. All that he has to do in order to adjust the mirror is, to make the two images of the star exactly coincident with each other, by turning one or both the adjusting screws, as the case may require. When he sees the star single, then the adjustment is complete.

484 *Adjustment of the Index Mirror.*—This adjustment should be done by the instrument maker, and the observer ought to be careful not to disturb it by rough handling, or meddling with the screw.

But, should necessity require it, the adjustment of the index mirror is effected by turning the screw (or screws) at the back of it, till the following condition is satisfied.

Let the observer hold the instrument before him in a horizontal position, and in a level with his eye, having the index mirror D next his eye, and the graduated arc A B C away from him. On looking in the index mirror, as he thus holds the instrument, he will see the portion B C of the graduated arc reflected; he will at the same time see the arc B C itself. In fact, the arc B C, and its reflection in the mirror D, will appear to unite at B, and form one continuous arc. Now, the condition of perfect adjustment is this.—The arc B C and its reflection must not appear bent or broken at the place where they seem to unite, but they must appear to form one unbroken graduated surface, so that the reflection of the arc B C may look as if it was really the continuation of the arc B C itself.

This condition being satisfied, the observer may be sure that the index mirror is truly perpendicular to the plane of the instrument.

485 If this condition appears to be satisfied into whatever position we move the index arm D B, the axis, round which the arm turns at D, must be truly perpendicular to the plane of the instrument, and so far the instrument must be a good one. It requires a little practice, however, to see whether this condition is accurately satisfied or not. But extreme accuracy is not necessary in this adjustment.

486 *Dark Glasses.*—There are always a set of dark coloured glasses near the two mirrors D and E, which may be placed before them or not at pleasure. The use of these glasses is to destroy the excessive glare of the Sun, when it is necessary to make an observation upon him.

V. *Uses of Hadley's Sextant.*

487 Hadley's sextant may be used to observe the angular distance between two heavenly bodies in the manner we have explained. Thus, the Moon's distance from a fixed star may be observed, and the longitude thence determined, according to the method we have explained.

This is a peculiarly valuable method at sea, as Hadley's sextant is the only instrument that can be used for measuring angular distances on the unsteady deck of a ship. The observer at sea often lies on his back, in order to manage the instrument with greater ease and steadiness.

488 *Observation of Altitudes by means of Hadley's Sextant.*—If it be necessary, as it continually is, to observe the Sun's altitude at sea, the observer directs the telescope of the sextant towards the visible horizon (that is, the extreme boundary of the sea, where it appears to touch the sky,) holding the instrument in the same vertical plane with the Sun, as nearly as he can judge. He then makes the Sun appear in the field of view, and, by the tangent screw, in the manner already described, causes the image of the Sun just to touch that of the sea. In this manner he finds the angular distance of the Sun from the visible horizon—that is, the Sun's altitude above the visible horizon.

489 But since the visible horizon at sea is a little below the real horizon, in consequence of the observer being at some elevation above the surface of the sea, there must be an allowance or correction to obtain the true altitude of the Sun above the horizon. This correction is called the correction for the *dip of the horizon*. The manner of making it is explained in treatises on *Nautical Astronomy*.

490 Altitudes on land are observed by the aid of an artificial horizon. (See Article 473.) The telescope is pointed at the image of a heavenly body seen by reflection in the trough of mercury, and the heavenly body itself is brought into the field of view by moving the index arm, and made to coincide exactly with the image seen in the trough of mercury by means of the tangent screw. In this manner, the angular distance of the heavenly body from its image reflected in the trough of mercury is determined, and half that angular distance is the altitude of the heavenly body above the horizon, as we have explained in Article 472.

491 *Determination of the Latitude of a Place by Hadley's Sextant.*—We have already explained how the latitude of a place is found by observing meridian altitudes. For this purpose, the graduated circle with which we observe must be placed exactly in the plane of the meridian. Now, this we cannot do with Hadley's sextant, inasmuch as we hold it in the hand, and therefore cannot be sure whether it is exactly in the meridian plane or not. To obviate this difficulty, meridian altitudes are observed by means of Hadley's sextant in the following manner:—

The observer makes as good a guess as he can at the position of the meridian, either by means of a magnetic compass, or the pole star, or otherwise; and he commences his observations on the heavenly body whose meridian altitude he wishes to determine, a short time before it comes on the meridian. He observes several altitudes of the heavenly body in succession at short intervals, which he finds to increase for a certain time, and then to diminish; for the heavenly body culminates, or attains its greatest altitude, when it comes on the meridian. Hence, the observer has only to select the greatest of the altitudes he has observed, and that cannot differ materially from the meridian altitude, if the observations have been made quickly one after the other at the time when the observer perceives the altitudes to increase very slowly and then begin to diminish.

There is, however, a simple mathematical rule, called the Rule of Interpolation, by which the observer may determine the exact meridian altitude, and the time of transit across the meridian, from a few altitudes observed every five minutes or so about the time when the heavenly body comes on the meridian. In this manner, Hadley's sextant may be used with considerable accuracy to determine the meridian altitude and time of transit of a heavenly body.

492 The greatest altitude of a heavenly body is easily determined by gradually turning the tangent screw, so as to keep the body and its reflected image in contact as long as the body is ascending, and ceasing to turn the screw as soon as the body appears no longer to ascend. The reading given by the index will then be the greatest altitude of the body. It is important to observe, that though the greatest altitude may be thus found with tolerable accuracy, the time of the body's transit over the meridian cannot be found with any degree of exactness in this way, as a little consideration will show.

493 Hence the time at any place may be determined by means of Hadley's sextant, by observing the time of transit of the Sun, or any other heavenly body whose right ascension is known. (See Article 454, &c.) Thus Hadley's sextant may supply the place of a transit instrument; it is not, however, to be compared with a transit instrument as regards accuracy in determining the time of transit.

494 We may observe here, that when we speak of the altitude of the Sun, we mean the altitude of his centre, and therefore when we make the Sun's lower limb appear just to touch the sea, we take the altitude of the Sun's lower limb, and not of his centre. It is necessary to correct this error, which is often done by means of a table in the Ephemeris, or Nautical Almanack, which gives the number of degrees, minutes, and seconds, in the Sun's apparent semi-diameter, which must be added to the altitude of the lower limb, in order to give the altitude of the centre.

Sometimes the altitudes of the upper and lower limbs are observed, half the sum of which will be the altitude of the centre.

495 The same remarks apply to the Moon, but, one side of the Moon being generally dark and indistinct, the second method does not always apply, and therefore the altitude of the Moon's centre must be found by observing the altitude of the enlightened limb, and adding or subtracting the semi-diameter, according as the enlightened limb is lower or upper.

The apparent semi-diameter must be given in the Almanack, because it is a variable quantity, being greater or less according as the Moon or Sun is nearer or farther off.

Refraction.

496 We have alluded to the astronomical corrections in two or three places already, and explained in a former chapter the causes of some of them. Two of them are optical, arising respectively from a real and an apparent deviation of the light, which comes from a heavenly body to the eye, from its rectilineal course. Another correction arises from the observer's change of position, which produces a corresponding apparent change in the positions of the Sun, Moon, and planets, the stars being too far off to be affected by it. Lastly, the correction for *Precession and Nutation* is due to the actual motion of the Pole caused by the attractions of the Sun and Moon on the Earth, whose deviation from a perfectly spherical shape, combined with its rotation, caused the Pole by these attractions. We have only space to allude briefly to one of these corrections—indeed, the full explanation of them would require too much mathematical information on the part of the reader to admit of saying much about them here.

497 We have already explained the manner in which the refraction of light takes place when it comes from a heavenly body to the eye, by the refractive power of the atmosphere. This refraction always makes a heavenly body appear higher up than it really is, and that in a greater degree according as the body is nearer to the horizon. A body in the zenith is not affected by refraction; at 45° from the zenith it is elevated about 1′ by refraction, and at

the horizon as much as 33′; so that the amount of refraction increases rapidly towards the horizon.

498 The density of the atmosphere, as is well known, is continually changing, in consequence of the continual variations of pressure and temperature which, from various causes, are always taking place at the earth's surface. The barometer is an instrument which measures the pressure of the air, and therefore its density, provided we take proper account of its temperature. Now, the refractive power of a transparent substance increases with its density, and the atmosphere is no exception to this rule. Hence, the indications of the barometer must always be observed before we can make a correct allowance for the atmospheric refraction.

It appears that the refraction of the atmosphere mainly depends upon its density, and that it varies very little in consequence of changes of temperature or humidity.

499 Since refraction always makes heavenly bodies appear to be higher up than they really are, the correction for refraction must always be subtracted from the observed altitude of a body in order to find its true altitude.

The following formula gives the amount of the correction for refraction of a heavenly body not far from the zenith:—

Let z be the observed or apparent zenith distance of the body, and r the correction; then

$$r = 57'' \times \tan. z,$$

and the true zenith distance is $z + r$:

that is, in order to find the true zenith distance, as far as refraction is concerned, multiply the tangent of the observed zenith distance by 57″, and the result added to the observed zenith distance will give the true.

This supposes the barometer to stand at its mean elevation, about 29½ inches, and the thermometer at the mean temperature, about 50 Fahr. If this be not the case, we must multiply the above formula by the quantity $\frac{b}{29{\cdot}6}$ to correct for the barometer, and moreover by the quantity $\frac{500}{450 + t}$ to correct for the thermometer: b being the height of the barometer in inches, and t the degree of the thermometer, (Fahr.) The formula for r will therefore be—

$$r = 57'' \times \frac{b}{29{\cdot}6} \times \frac{500}{450 + t} \times \tan. z.$$

Furthermore, if the body be not near the zenith, instead of tan. z, we must put tan. $(z - 230'' \tan. z)$; that is, the formula for r will be—

$$r = 57'' \times \frac{b}{29{\cdot}6} \times \frac{500}{450 + t} \times \tan. (z - 230'' \tan. z.)$$

This formula is nearly coincident with one given by Bradley, only it has $230''$ tan. z, instead of $3 \times 57'' \times$ tan. z, as in Bradley's formula.

The rule, then, for finding r is as follows:—Multiply the tangent of the observed zenith distance (z) by 230″, subtract the result from z, and find the tangent of the remainder, which multiply by 57″. The quantity thus obtained must be multiplied by the height of the barometer (b), and divided by 29·6; also, it must be multiplied by 500, and divided by the temperature (t), increased by 450. The final result thus obtained is the value of r, which must be added to z, and the true zenith distance is thus obtained.

This is the only correction necessary if the heavenly body be a star; but if it be the Moon, another correction, called *parallax*, must be applied: of this, however, we cannot speak here.

For the sake of the reader who does not understand what a tangent is, we give the following short table, in which the tangent for every degree is given. By this table he may calculate the value of the refraction. Practical men generally find the refraction, not by a formula, but by a table of refractions, in which the value of the quantity 57″ tan. $(z - 230'' \tan. z)$ is given for all the values of z between 0° and 60°. The angles are given in degrees, and the tangents to three decimal places, which is sufficient for the present purpose.

Angle.	Tangent.	Angle.	Tangent.	Angle.	Tangent.
1	·017	21	·384	41	·869
2	·035	22	·404	42	·900
3	·052	23	·424	43	·933
4	·070	24	·445	44	·966
5	·087	25	·466	45	1·000
6	·105	26	·488	46	1·036
7	·123	27	·510	47	1·072
8	·141	28	·532	48	1·111
9	·158	29	·554	49	1·150
10	·176	30	·577	50	1·192
11	·194	31	·601	51	1·235
12	·213	32	·625	52	1·280
13	·231	33	·649	53	1·327
14	·249	34	·675	54	1·376
15	·270	35	·700	55	1·428
16	·287	36	·727	56	1·483
17	·306	37	·754	57	1·540
18	·325	38	·781	58	1·600
19	·344	39	·810	59	1·664
20	·364	40	·839	60	1·732

CHARTOGRAPHY.

NEITHER the nature of the present work, nor the space to which we must limit ourselves, permits our treating *in extenso* of Chartography; a subject which, if fully developed, would of itself fill a large volume and require a great many plates. We must accordingly confine ourselves to a brief notice, in which, however, we will endeavour to give all the information we can, consistently with a popular work like the present.

By Chartography, in its widest sense, is understood the construction and delineation of maps, charts, and plans, no matter for what special purpose, upon what projection, or on what scale. The direct object of maps is to represent the whole or some portion of the Earth's surface; but as this surface is spherical, it is evidently impossible to reduce it, or any part of it, to a flat surface, without a greater or less distortion of its details: whence it follows, that the only way in which the Earth can be accurately figured is by a globe; and even then the elevations of the surface cannot be shown in their proper relief, as the highest mountains would be less than the thickness of the paper on an eighteen-inch globe.

TERRESTRIAL GLOBE.—An artificial globe is a miniature representation of our planet, with its grand divisions of land and water, and on which all the regions of the Earth may be correctly laid down as regards position, form, area, and distances. We do not mean to say, that even on the best globes everything is mathematically correct, for we are far from possessing the exact latitudes and longitudes of all places on the surface of the Earth, and until we have these, the position of many places, even on the most perfect globes, must be regarded only as approximations to truth. But as far as positions are determined, they may be more exactly represented on a globe than on any map. The ordinary size of globes, however, does not admit of much detail, and although very large globes have been constructed, they are rather objects of curiosity than of practical utility. Even a four-foot globe takes up a great deal of room, and is only fit for large libraries or public teaching. In very large globes, again, any small portion of the surface has so little convexity, that if the country contained in such portion were projected on the plane surface of a map, the forms would hardly be distorted, and the relative distances of places so near the truth, that the globe, in such case, would, as far as such country was concerned, offer no great practical advantage. Globes are, nevertheless, very desirable, both as conveying, upon simple inspection, a much more correct notion of the true forms of regions, and the relative positions of places, than can be done by maps, and as enabling us to solve a great many interesting problems: the best adapted for general use are of eighteen inches diameter.

The most accurate globes are those on which the details of the surface are drawn upon the globe itself directly, and this is always done in very large globes; but such are, of course, very expensive. The usual mode is to cover the globe with a map constructed and engraved expressly for the purpose, in a number of separate pieces or slips, called *gores* (in French, *fuseaux*), generally twelve, fifteen, or twenty-four, bounded each by meridian lines, and terminating at the North and South Poles, or at the Arctic and Antarctic circles, in which latter case, two circular pieces are required for the two frigid zones. As each gore is a flat surface, it can be made to coincide with the convex surface of the globe only by the paper itself yielding or stretching, and it will be easily conceived, that the pasting on of the paper, so that each separate gore shall exactly meet without tearing, presenting folds, or overlapping, is a very difficult and delicate operation. When the pasting is dry, the globe is coloured and varnished, and then mounted. There are various ways of setting up a globe; the most usual is to fix it within a brazen meridian, set in a horizontal frame, called the *wooden horizon*, and as the mounting requires as much care as is necessary for pasting the map, we are not to be surprised if many globes are very imperfect, a fact of so much the more importance as a globe is useless unless it be perfect in all respects. We therefore recommend to every one who would possess a really good globe, to examine it well before purchasing. The characteristics of a perfect globe are as follow:—

1. All the meridional edges of the slips or gores must join so perfectly as to form continuous fine circles, neither overlapping nor failing to meet.

2. All these circles must be true, which is seen by bringing them successively under the *Brazen Meridian*, with which they should correspond all the way round: if they do not, the fault may be either in them or in the brazen meridian itself, which is not perhaps in a true plane.

3. When the poles are brought to the wooden horizon, in what is termed the *right position* of the sphere, each meridian brought successively to the wooden horizon, should correspond with it all the way round.

4. The brazen meridian must be in a plane exactly perpendicular to that of the wooden horizon, which it is, if, while any one meridian on the globe corresponds with it all the way round, the equator corresponds at the same time with the wooden horizon all the way round.

5. Every one of the parallels of latitude must form continuous and perfect circles all the way round, and, on turning the globe, must each of them correspond in all its parts with the same precise point on the brazen meridian.

6. When the equator is made to correspond with the wooden horizon, the two zero points of the brazen meridian must correspond exactly with the upper surface of the wooden horizon, in which case, they will, of course, also correspond exactly with the equator on the globe.

7. All the degrees on the equator, on the ecliptic, on the first meridian, drawn on the globe, and those on the quadrant of altitude, when there is one, must be exactly similar. In order to ascertain whether they are so, take with the compasses any number of degrees from any one of these circles, and apply the measure to all the other circles, and see if it intercepts on them all and everywhere the same number of degrees. In like manner, the degrees on the brazen meridian and on the wooden horizon must exactly correspond to each other.

8. The brazen meridian must slide with ease through the notches cut to receive it in the wooden horizon, but must not be so loose as to shake in it.

9. As the globe is turned round, every part of its surface must be equidistant from the brazen meridian and from the wooden horizon, and the nearer the better, provided all be so true that there is no danger of rubbing. This is the true criterion of a well set globe.

10. The globe must be so truly balanced upon its poles, as to remain quite motionless the moment you cease turning it, the poles being placed horizontally.

11. In the right and in every other position of the globe, except the parallel, the equator, on turning the globe round on its axis, must correspond to the same points on the wooden horizon, which points are at 90° from the intersection of the brazen meridian with the horizon.

12. Every part of the polar and tropical circles must correspond with their known latitudes on the brazen meridian.

With respect to the geography of the globe itself, it is necessary to see that it contains all the latest corrections of positions and discoveries of importance, that no place of real note is omitted, that the names be well and distinctly engraved, and that they be not too crowded. Lastly, the wooden horizon must be examined with reference to the several circles marked upon it, each of which must be properly graduated, and their several portions in their true places, as regards the other circles and the globe itself.

We have spoken only of the terrestrial globe, and of the more usual way of setting or mounting it. There are various other modes,[*] but which our limits will not admit of our detailing. As for the *Celestial Globe*, it is destined for astronomical purposes, and is therefore foreign to our subject.

It is only by means of a globe, we have said, that the Earth's surface can be correctly represented; but as a globe is neither portable, nor capable, from its small size, of exhibiting the details which are often required, we must have recourse to maps, the great and indeed only disadvantage of which consists in the impossibility of truly representing a spherical on a flat surface.

PROJECTION OF MAPS.—Different methods have been devised for the construction of maps, so that the real figure of the several regions of the Earth shall be as little distorted as possible. These constructions are called *Projections*. We cannot here enter into the elaborate researches, the complicated analyses to which some of the greatest mathematicians have subjected the different projections and their modifications; we will merely explain the geometric construction of such as are most commonly employed.

There are five principal projections—namely,

1. The Orthographic,
2. The Stereographic,
3. The Globular, or Equidistant,
4. The Conical, and
5. The Cylindrical, or Mercator's.

In the orthographic, the stereographic, and the globular projections, the *plane of projection*, or the flat surface on which the map is drawn, is supposed to pass through the centre of the globe; but in the first, the orthographic, the eye of the observer is supposed to be at an unmeasurable distance; in the second, or stereographic, it is presumed to be at the surface of the globe; and in the third, or globular, it is supposed situated at a point whose distance from the surface of the globe is equal to the sine of the angle of forty-five degrees.

In order the better to understand how, in the several cases, the picture is formed upon the plane of projection, it is customary to imagine both that plane and the globe to be transparent. Now, it is clear, that as we see everything we look at through a pane of glass, as if it were drawn upon such plane of glass, so in the above supposition, all the details of the hemisphere on the opposite side from the spectator would appear to him as though they were drawn upon the transparent diaphragm or plane of projection. But unless this supposition be limited, it is more likely to create a confusion of ideas than assist the student in forming a right conception of the subject; for while, in considering the geographical position of any place on the Earth's surface, we always refer to our own position as external, and thus say the east is to the right when we face the north, it is evident that in a picture traced according to the above supposition, we see the objects reversed, so that what is really to the east appears to be to the west. The fact is, nothing of the surface of the sphere is projected but its great and small circles, and so far only as these are concerned, is it safe to admit the imaginary transparency alluded to. When once the parallels of latitude and the meridians are projected, the several regions of the Earth are laid down upon the map in conformity with the latitudes and longitudes of their several parts.

THE ORTHOGRAPHIC PROJECTION.—In this projection, the eye of the spectator is conceived to be at such a distance from the plane of projection, that the visual rays which traverse it in their passage from different points of the hemisphere beyond, are all parallel and fall perpendicularly upon it, whence it follows that equal spaces on the hemispherical surface are represented by unequal spaces on the plane of projection.

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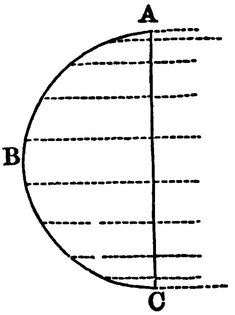
[*] A mode of mounting globes, far superior to that usually adopted, was proposed by Adams, and executed with improvements by C. Covens: a description and plate of it will be found in Malte Brun's *Précis de Géographie Universelle*.

Fig. 1

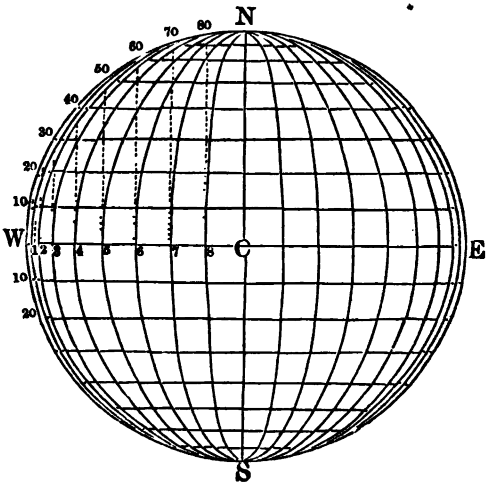


Thus, let A B C (fig. 1) represent a section of the hemisphere divided into nine equal arcs, and A C a section of its plane of projection. Now, if from the several points on A B C, parallel visual rays be drawn perpendicularly through A C, it is evident the spaces intercepted between these rays will be unequal, while the points whence they proceed are equidistant from each other. It will further be observed that those nearest the centre approach nearest to equality, while those further removed from it diminish in proportion to their distance.

As all the parallels of latitude are in planes perpendicular to the plane of projection, they will be projected in straight lines, while all the meridians, except the central one, will be projected in elliptical curves.

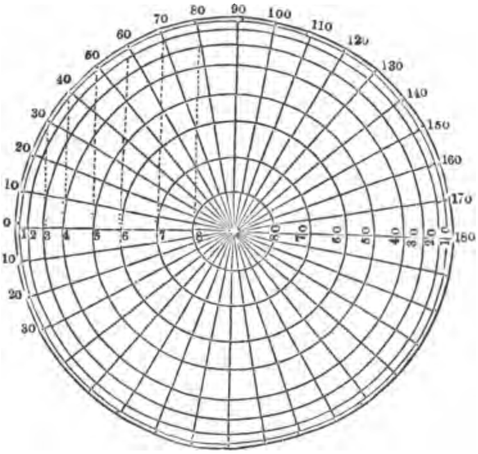
The mode in which the orthographic projection is graphically constructed is represented (fig. 2). A circle N E S W is drawn, representing the meridian bounding the plane of projection. Two diameters, W C E and N C S, are next drawn at right angles to each other: the former being the projection of the equator, and the latter that of the central meridian. The quadrants of the circle are then respectively divided into spaces of ten degrees each, marked 10, 20, 30, &c., from the extremities of the equator towards the poles N and S. From these points draw lines parallel to the equator, and these will represent the parallels of latitude for every ten degrees. Now, from their extremities, let fall perpendiculars upon the equator, and through their points of contact with it, draw ellipses with N C S for a common transverse axis, and with C 1, C 2, &c. respectively for half their conjugate axes. These curves will be the projections of the several meridians.

Fig. 2



The same projection may be effected on the plane of the equator. Thus, (fig. 3,) describe a circle to represent the equator, the centre of which circle will represent the pole. Then draw two diameters at right angles to each other, and divide each quadrant, as before, into nine equal parts. From these points draw diameters to the corresponding divisions of the opposite quadrant, and these lines will represent the meridians, any one of which being taken for the first, the others must be numbered 10, 20, 30, &c., half way round on either side, to 180. Next let fall perpendiculars from the divisions of one of the quadrants on one of the radii, and through the points of intersection 1, 2, 3, &c., describe circles to represent the parallels, marking them from the outer to the inner with the numbers 10, 20, 30, &c. for the degrees of latitude.

Fig. 3

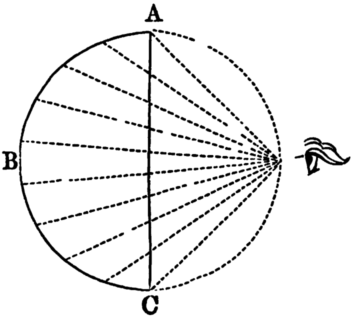


As all the quadrilateral spaces in figs. 2 and 3 represent ten degrees of longitude and as many of latitude, their simple inspection shows that, with the exception of such places as occupy the centres of the projections, the several regions, particularly those nearest the circumference, must be most dreadfully distorted in form, and diminished in magnitude.

The Stereographic Projection.—This projection differs from the former, in presuming the eye of the spectator placed at the surface of the globe and exactly opposite the central point of the plane of projection, which, as in the former case, is supposed to divide the globe into two halves, the farthest of which from the observer being that whose lines are to be projected.

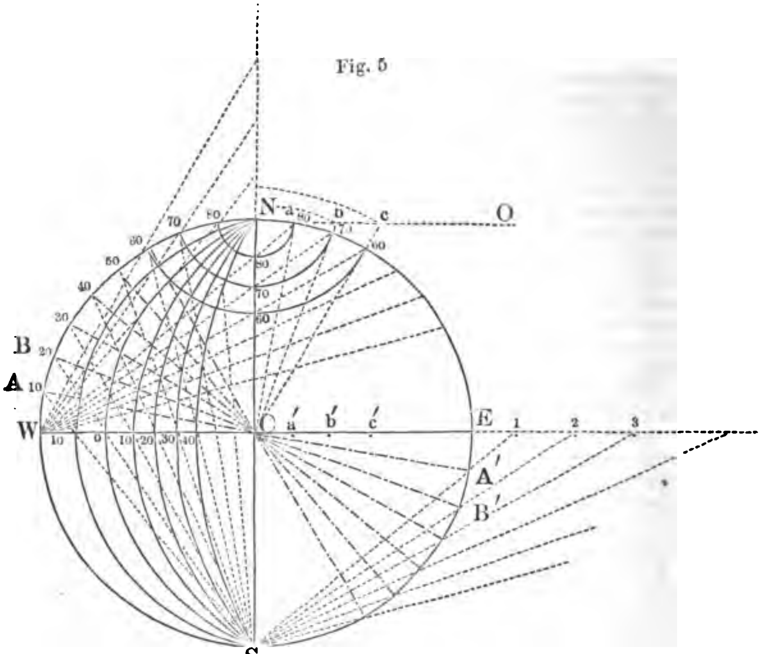
From the proximity of the eye, the visual rays, instead of being parallel, as in the former case, all converge from the hemisphere to the point of projection, so that while equal spaces on the hemisphere are still represented by unequal spaces on the projection, the inequality is not near so great as in the former case, and the spaces, instead of diminishing from the centre towards the circumference, diminish in the contrary direction—namely, from the circumference towards the centre. This is rendered evident by fig. 4, in which the visual rays, passing from the equal spaces, into which the hemisphere, represented in section by the arc A B C, is divided, intercept spaces in the plane of projection (of which A C is the section) so much the larger as they recede from the centre. This inconvenience, however, is in part compensated by the property enjoyed by this projection of representing all the figures on the sphere by *similar* figures, and consequently all the right-angled quadrilateral spaces formed on the sphere by the intersections of the meridians and parallels are projected into similar figures, so that the countries are not distorted in form, as is the case in the orthographic projection.

Fig. 4



The stereographic projection of a hemisphere on the plane of a meridian is thus effected. Describe a circle N E S W (fig. 5) representing the meridian that circumscribes the plane of projection, and draw two diameters, N C S and W C E, the former to represent the projection of the central meridian, and the latter that of the equator. Then divide the quadrants from the equator to the poles into 6 or 9 equal parts, according as it is required to have the parallels at 15 or at 10 degrees apart, (in the figure they are at 10 degrees),

Fig. 5



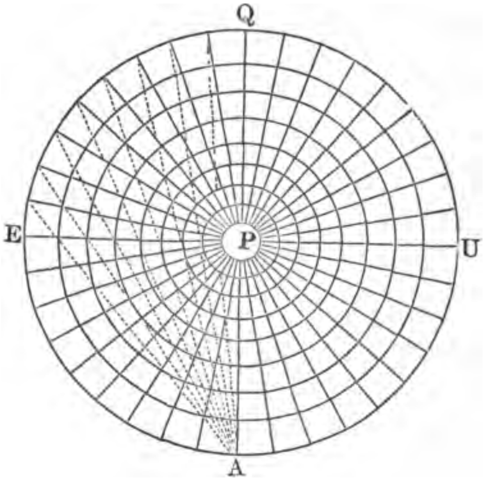
and number them successively 15, 30, 45, &c., or, as in the fig., 10, 20, 30, &c. From S draw lines to the several divisions, as S 10, S 20, &c., and their intersection with the line W C E will be the points through which the circular arcs representing the meridians must be described. For the parallels, draw lines, in like manner, from either extremity of the line W C E to the divisions of the opposite quadrant, and their intersection with the central meridian will be the points through which the arcs of the parallels are to be struck.

The places of the centres from which the parallels are described, depend on the principles which determine this projection; one of which is, that the distances of the centres of the parallels from the centre C of the projection, are equal to the secants of their distance from the pole, and accordingly, if the length of these secants respectively be marked off from C on the prolongation of S C N, they will give the centres from which to describe the parallels.

Thus, if a tangent N O be drawn parallel to W C E, and lines drawn to it from the centre C through the divisions 80, 70, 60, &c., these latter will be the secants respectively of the angular distances of these parallels from the pole: C a the secant of 10 degrees, or the distance of the 80th parallel from the pole; C b the secant of 20 degrees, or the distance of the 70th parallel, and so on. Transport these distances successively from C on C N prolonged, and they will give the centres sought; or, what is the same thing in theory, though impossible in practice, draw lines from W through the divisions of the quadrant on the same side of the central meridian, until they meet the prolongation of C N, and half the distance between these intersections and the corresponding ones on N C will be the places of the centres.

Another principle of this projection is, that the distance of the centre of projection of any great circle oblique to the plane of projection, is equal to the tangent of the angle at which the circle is inclined, and its radius is equal to the secant of that angle. Hence the centres for describing the meridians may be found by transporting the tangents of 10, 20, 30, &c. degrees already found—viz., N a N b &c. to the line C E and its prolongation, as shown at C a′, C b′, C c′, &c., and from these points, with the secants, likewise found as C a, C b, &c. for radii, describe the meridianal arcs. Or the centres for the meridians may be found thus: from the divisions of the quadrant W N draw diameters to the opposite quadrant, as A A′, B B′, &c. Through A′, B′, &c. draw lines from S, and produce them till they meet the prolongation of W C E in 1, 2, 3, &c.; then half the distances respectively between these points, and the intersections previously found of the line W C, will be the centres sought: that is, the middle a′ of the line 1, 10 will be the centre for striking the meridian S 10 N, the middle b′ of the line 2, 0, the centre for S 0 N and so on. It will be observed that these points a′ b′ &c. are precisely those that were found by transporting the tangents N a, N b, &c. to C E.

Fig. 6



The application of this projection to the plane of the equator is exceedingly simple. Thus, (fig. 6) describes a circle E Q U A to represent the equator; draw two diameters at right angles to each other; divide each of the quadrants thus formed into nine equal parts, and from the divisions on E Q draw lines to A; their intersections with E P will be the points through which circles must be described from P, the pole, to represent the parallels; while radii drawn from P to all the divisions on the equator will be the projections of the meridians.

As the globe may be divided into two hemispheres in an infinity of ways, so many different planes of projection may be chosen, besides those on a meridian or on the equator, and accordingly hemispheres are sometimes projected on the plane of the rational horizon of some particular place, as on the horizon of Paris, as has been done by Lapie; on the horizon of London, as has been done by Mr. W. Hughes, &c. These projections, called *horizontal*, (as those on the plane of a meridian are called *equatorial*, and those on the plane of the equator are called *polar*,) are extremely interesting, but the construction is somewhat complicated: we shall explain it as applied to the horizon of London.

Describe a circle N E S W, (fig. 7,) and draw two diameters, N S and W E, at right angles to each other. From N, mark off on the quadrant, N W, a number of degrees equal to the latitude of the place, or height of the pole above the horizon, (in the present case,) 51° 30′, and P will be the place of the superior pole. From it, draw the diameter P P′, and P′ will be the place of the inferior pole. The eye being at E, draw E P, and its intersection with N S in p will be the projection of the upper pole. Draw also the line, E P′, and produce it till it meet the prolongation of N S in p′, then p p′ will be the projection of the meridian P P′. Now set off on either side of P as many times ten degrees, or the ninth part of a quadrant, as there are parallels that distance apart, between the pole and southern part of the horizon, (in the present case twelve,) and draw lines from these points to E, the intersection of the ninth of which with the line N S, south of the pole p, at Q, will be the point through which the projection of the equator must pass, and the other intersections, the points for the several parallels, the centres for which and for the equator, will necessarily be on N S and its prolongation, and are determined by finding the middle point between the corresponding intersections 80 and 80, 70 and 70, &c.

For the meridians, it must be remembered that p p′ represents the poles, and the line joining them, a meridian passing through the middle of the hemisphere, (the meridian, in fact, of London, whose place is at L, in the zenith of its horizon, N E S W,) and accordingly, all the other meridians must meet this one at the poles, under angles equal to their difference of longitude from this meridian. If then we bisect the diameter p p′ in C, and with C p for radius, describe the arc W p E, it will be the projection of a meridian at 90° from the meridian of London.

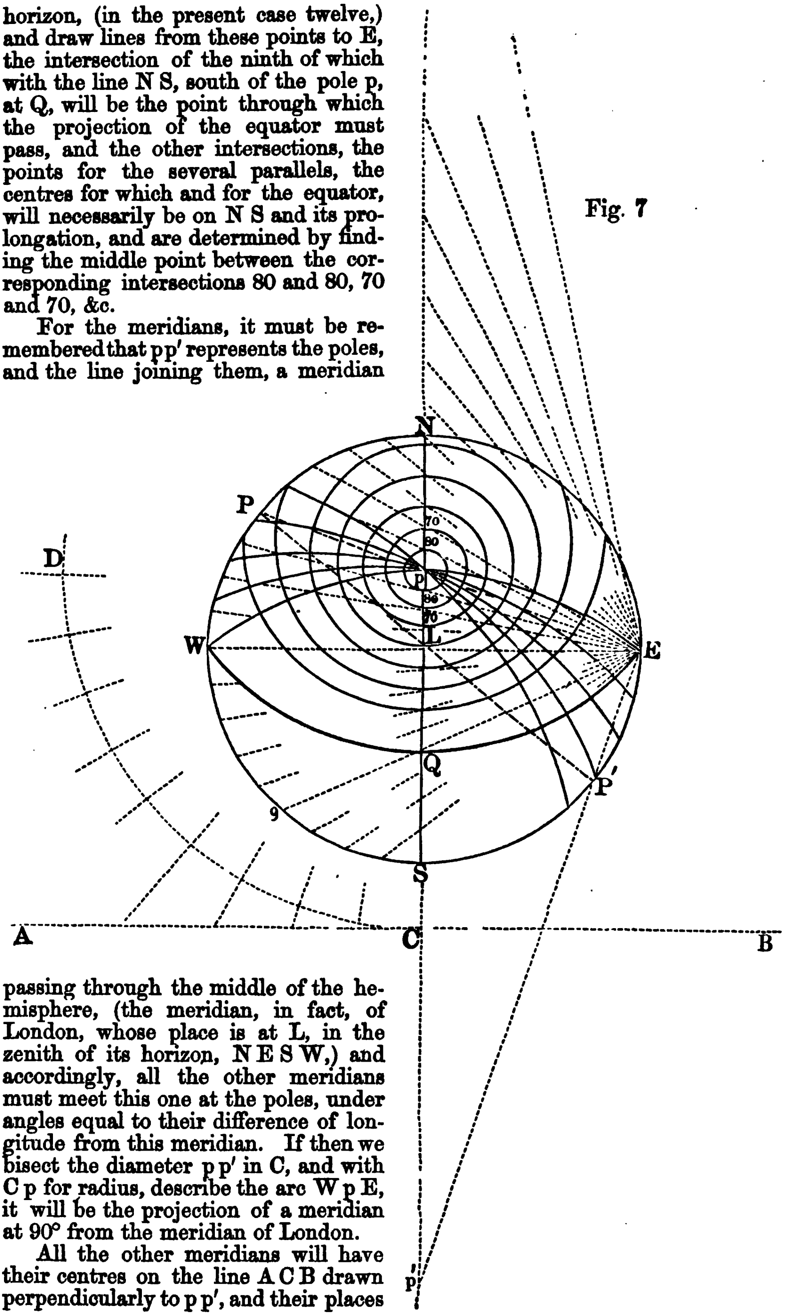


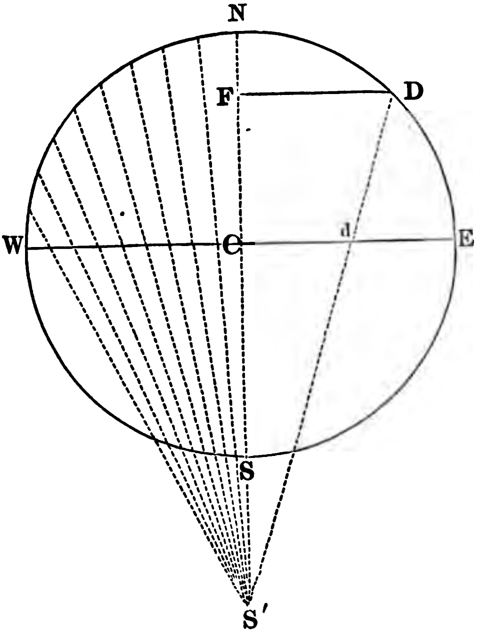
Fig. 7

All the other meridians will have their centres on the line A C B drawn perpendicularly to p p′, and their places are found thus:—From p, as a centre, describe a circle with any radius, say p C, and divide it into thirty-six equal parts, beginning at C. Then from p, through these divisions, draw lines till they meet the line A C B, and their intersections with it will be the centres for describing the meridians.

In the two figures, 5 and 7, we have drawn only a few of the meridians and parallels, in order not to create confusion by the great multiplicity of lines: it will be self-evident to the reader, that whatever constructive operations are described for one side of the central meridian, must also be performed on the other in the opposite direction, in order to complete the projection of all the circles. It is also with a view of avoiding too many lines that we have not traced the *polar* nor the *tropical circles*, but as their distance respectively from the poles and from the equator is known to be twenty-three and a half degrees, nothing more is necessary for tracing them than to set off those distances on the quadrant from the N and S points of the central meridian, and from the E and W points of the equator, and then describe these circles by the same processes as have been explained for the parallels.

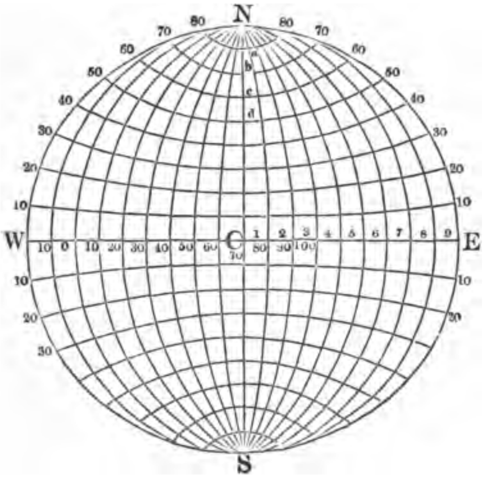
The Globular Projection.—We have seen that, whereas in the orthographic projection, equal spaces on the globe become very much contracted towards the extremities of the projections, they are, on the contrary, greatly enlarged at those parts in the stereographic. In order to rectify these opposite defects, La Hire conceived that between the indefinite distance at which the eye is supposed to be in the case of the orthographic projection, and its position at the surface of the sphere in the stereographic projection, there must be a point from which they would be, if not wholly compensated, at least greatly reduced, and this point he determined to be at a distance from the surface of the sphere equal to the sine of the angle of 45°, or what is the same thing, if the meridian N S (fig. 8) be 200 parts, it must be prolonged 70 of these parts to S′. If, then, visual rays be drawn from S′ to the divisions of the quadrant, their intersection with C W will determine spaces much more equal than in the former projections. Indeed, if F D be the sine of 45°, it is evident that a line drawn from S′ to D will exactly bisect the radius C E in d, so that the equal arcs E D and D N are represented by equal spaces E d and d C. All other arcs, however, will not be so exactly represented by equal spaces. The geometrician, Parent, found that by placing the point S′ at only 59½ parts from S, all the inequalities of the spaces on C E or C W would be the least possible; but in order to have the zones of the hemisphere respectively proportionate to those of the sphere,

Fig. 8



the point S′ must be placed at 110½ parts from S. Still this projection, however modified, is very defective, inasmuch as the parallels and the meridians do not intersect each other in it at right angles. It is, moreover, difficult to construct, as all the parallels and meridians are represented by ellipses.

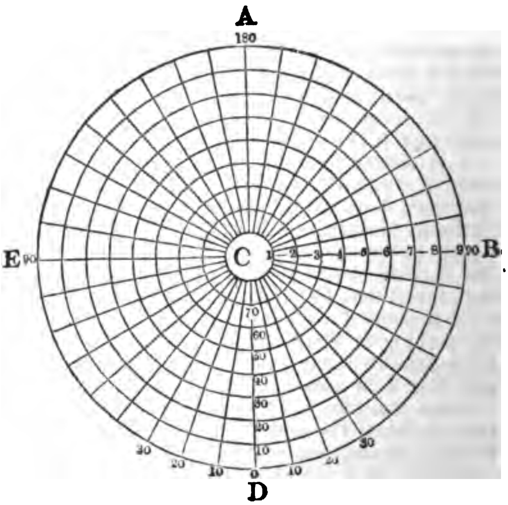
Fig. 9



The Equidistant Projection.—We have said that in the globular projection, the spaces representing equal arcs of the sphere are *nearly* equal; whenever, therefore, this projection is used, there is very little disadvantage resulting from rendering them exactly equal, and when this is done, the projection is called the *Equidistant*. Its mechanical construction is as follows:

Describe a circle N E S W, (fig. 9,) and draw two diameters, N C S for a central meridian, and W C E for the equator. Divide each of the quadrants into nine equal parts, and each of the semi-diameters, C N, C E, &c. also into nine equal parts. Then find on the prolongation of N S both ways, the centres of circles whose arcs must pass through 80 a 80, 70 b 70, 60 c 60, &c., and these arcs, described both on the North and on the South of the equator, will be the parallels. In like manner, find on the prolongation of W E both ways, the centres from which to strike the meridians, all of which must join at the poles, and pass through the points 1, 2, 3, 4, &c. Having selected that meridian which is intended for the first, number the others successively 10, 20, &c. to the right and left of it.

Fig. 10



For a polar projection, (fig. 10,) describe the circle A B D E; this will represent the equator. Draw two diameters at right angles to each other, A D and E B, for two meridians at ninety degrees apart. Divide each quadrant into nine equal parts, and also each of the four radii C A, C E, &c. into the same number. From the centre C describe circles passing successively through the points 1, 2, 3, &c.; these will be the projections of the parallels. Now draw lines from the several divisions of the quadrants through the centre to the divisions on the opposite quadrants, and these diameters will be the projections of the meridians. Place the numbers denoting the degrees of latitude 10, 20, 30, &c., upon the central meridian from the equator towards the pole, and from the same meridian place the degrees of longitude on either side half round to 180°.

Having thus described the three principal projections employed for representing the hemispheres, whether North and South, East and West, or those bounded by the rational horizon of any place and of its antipodes, we will now pause a moment to recapitulate their several defects and relative advantages; as to the defects, in some shape or other, they are unfortunately irremediable.

In the Orthographic projection—1st. The parallels are projected in straight lines, and the meridians in ellipses. 2nd. Equal spaces and distances on the sphere are represented by unequal spaces. 3rd. The spaces *lessen* successively from the centre towards the circumference of the hemispheres. The consequence is, that while the central parts are nearly in their correct proportions, those at a distance from the centre are terribly distorted in form and diminished in magnitude.

In the Stereographic projection—1st. The parallels and meridians are all projected in arcs of circles. 2nd. In this, as in the Orthographic projection, equal spaces and distances on the sphere are represented by unequal spaces. 3rd. These spaces *increase* successively from the centre towards the circumference, so that the parts near the circumference are much too large in relation to those near the centre; but as the parallels and meridians intersect each other at right angles, the *forms* of the several regions are better preserved than in the Orthographic projection.

In the Globular and Equidistant projections (which differ chiefly in this, that in the former all the circles of the sphere are projected in ellipses with small eccentricity, whereas in the latter they are projected in perfect arcs of circles)—1st. Equal spaces on the sphere are represented by equal or nearly equal spaces on the projection, and accordingly the *relative dimensions* of the several countries are more correctly obtained; but as the rectangular spaces on the sphere are not represented by similar spaces on the projection, the *forms* of the countries are greatly distorted, and the more so the further from the centre; because the nearer to the circumference, the more do the intersections of the meridians and parallels differ from right angles. Nevertheless, from the great ease with which the equidistant projection is executed, it is very frequently adopted. As for the Globular, some geographers, La Croix amongst others, give it the preference over the two other projections. We, for our own part, prefer the Stereographic.

It is almost needless to observe, that the defects of these several projections are equally sensible, whether they be equatorial, i. e. on the plane of a meridian, or polar, i. e. on the plane of the equator. This will be evident from simple inspection of the figures; though in the case of the Stereographic projection, the enlargements affect the opposite regions in the equatorial to what they do in the polar projection, so that, in some degree, the judgment may be rectified by using both. In the case of the Equidistant projection on the plane of the equator, it will be seen that the degrees on the equator and on the parallels immediately adjacent, are much larger than the degrees on the meridians, and accordingly, countries situated in the equatorial regions must have their dimensions in longitude greatly exaggerated.

Upon the whole, as these several projections are never used but for planispheres, the defects we have endeavoured to point out are not perhaps of any great practical consequence, particularly as this kind of map is only consulted with a view to having a general idea of the relative bearings and positions of the great divisions of the terraqueous globe; and certainly, of these projections the most interesting and instructive are those on the plane of the horizon of the capital of the country for which the map is designed. It is indeed matter of surprise that we see none such constructed on a large scale. Unfortunately, but few map-makers will take the trouble to construct them.*

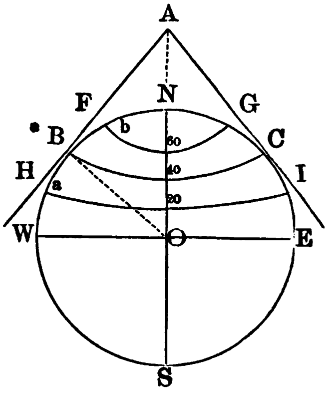
A very useless custom still prevails with some map-makers of representing on their planispheres and globes the tracks of the 'Endeavour' and 'Resolution.' Far be it from us to detract in the least from the merits of the immortal Cook; his glorious achievements are too indelibly impressed on the national mind, and have had too great an influence on the commerce of our country; have too largely contributed to its fame ever to be forgotten; but we think that what was not only justifiable but highly proper at the time, from the novelty of Cook's explorations and the wonders brought to light by his circumnavigation, is no longer so, now that vessels of all the great maritime nations have followed in his track and made the tour of the globe, and we hold that no map should contain a single feature that is unnecessary.

We come now to the other projections we have named. As the former were, so to say, perspective representations, those that remain to be spoken of are more properly developments.

The utter impossibility of fulfilling all the conditions of a perfect representation of a spherical on a flat surface by any of the means we have detailed, led to the search for others less defective. It was considered that as cones and cylinders are simple curves, susceptible of being developed or opened out, without that operation effecting the slightest alteration of these surfaces, or the distortion of anything represented upon them, and that as these figures correspond pretty nearly with portions of a sphere, the latter might be transferred to the former, whose development would then give nearly correct representations.

The Conic Projection.—Let N E S W (fig. 11) represent a sphere, and A B C a cone circumscribed about it, so as to touch it at the latitude of forty degrees. It is evident, that at the parallel of contact, the spherical and the conical surfaces correspond exactly, and this parallel will be represented on the development of the cone by a circle, drawn from its apex A, with the radius A B. Consequently, any portion of this parallel on the sphere will be identical with its corresponding portion on the cone. Not so, however, with the parallels above and below it, as those of 20° and 60°. Here the sides of the cone recede from the sphere, and accordingly the circles representing these parallels, and drawn upon the cone from A, with A H and A F as radii, will be somewhat too large. The difference nevertheless is but trifling, as the surface of the spherical zone comprised between the given lati-

Fig. 11



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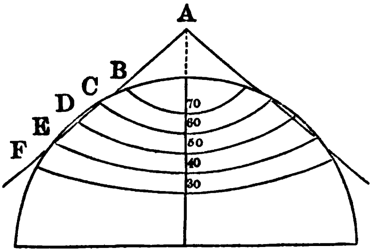
* Mr. W. Hughes has published a very beautiful map of the world, in two hemispheres, projected on the rational horizon of London and its antipodes; London being in the centre of one hemisphere, and a point a little to the S. E. of New Zealand in the middle of the other. Concentric circles are drawn round these centres at the distance of 1000 miles apart, and the points of the compass being marked round the borders, the bearing and distance of any place from London are at once ascertained. It will further be seen by this map, that London is in the exact centre of all the land portion of the earth; the opposite hemisphere being all water, with the exception of the tail-piece of South America, and of Australia and its surrounding islands. This little map is exquisitely engraved, and is highly interesting on every account.

tudes is nearly the same as that of the conic frustrum H F G I; the line H F differing but little from the arc a b.

In constructing this projection, it is usual to make the cone coincide with the central or mean parallel of the country it is intended to map, and accordingly, all the distances along that parallel are as exactly laid down on the map as on the sphere itself, whereas those on the extreme northern and southern parallels will be a little too long, by an absolute quantity, however, so much the less as the spherical zone is the more contracted in the direction of the latitude, and *vice versa.*

There are, however, other modes of conceiving the conic projection. Of these, the best is that which was adopted by Delisle de la Croyère for a general map of Russia. According to this method, the cone is supposed to be *inscribed* instead of being *circumscribed,* and it is made to enter and leave the sphere in such a manner that it coincides with it at *two* parallels, each of which is intermediate between the central one, and one of the extremes. By this means, the distances on the map are perfectly correct along the two parallels, where the surface of the cone coincides with that of the sphere, as at C and E (fig. 12), while at the intermediate parallel D 50, the distance is a little too short, and at the extreme parallels 30 and 70, a little too long. The errors are thus more equally distributed over the map; and when the extent of latitude embraced by the map does not extend beyond thirty or forty degrees, the representation approaches very nearly to exactitude.

Fig. 12

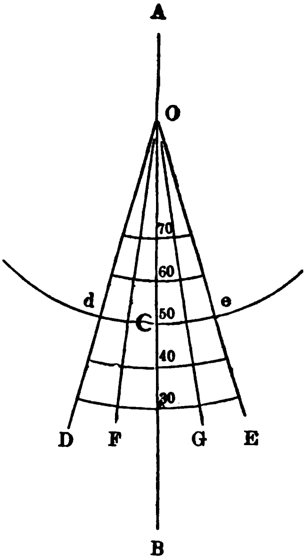


In the conic projections, strictly so called, the parallels are always arcs of circles, and the meridians straight lines drawn from the common centre of the circles, the apex of the cone. This rule has, however, been occasionally modified in the way we shall presently describe. The mechanical construction of the pure conic projection is as follows:—

When a hollow cone is placed upon a sphere, the side of the cone forms a tangent to the angle comprised between the axis of the cone and a perpendicular let fall from the point of contact of the cone with the surface of the sphere to the centre of the sphere, and is a co-tangent of the complement of that angle. Thus, in fig. 11, the side A B of the cone A B C, is the tangent of the angle A O B, and co-tangent of the angle B O W. But the arc W B expresses the latitude of the central parallel B 40 C, with which the cone coincides; and as this holds good, whatever be the parallel chosen, it follows that in determining the projection, in the case of a circumscribed cone, the side of the cone must be made equal to the co-tangent of the latitude of the middle parallel. The absolute length must be found in degrees and minutes of latitude thus:—

Draw an indefinite line A B (fig. 13) to represent the central meridian of the map, and from any convenient point, say C, through which it is intended to make the central parallel (say that of fifty degrees) pass, set off above and below, and at such distance apart as shall represent ten degrees of latitude, according to the proposed scale of the map, the points through which the other parallels are to be drawn. This done, say—As the circumference of a circle, or 3·1416, is to its diameter or 1, so are the 360 degrees of the circumference to x degrees, the number contained in the diameter. This will be found to be 114·591 degrees, and accordingly the radius will contain the half of this, or 57·295; and this being multiplied by ·839, the co-tangent of 50 degrees, (the latitude of the central parallel,) gives 48·070505, or 48° 4′ 13″, which, being taken from the marked off latitudes as a scale, and set off from

Fig. 13



C towards A, determines the length of the side of the cone or point O, from which the parallels through 60, 40, &c. are to be struck, and to which all the meridians must converge. Strike from the point O, thus found, an indefinite arc through C; next find the angle which the extreme meridians of the intended map must make on either side with the central meridian O B. For this we must consider, 1st. That the number of degrees contained in two arcs of equal length is as their radii, and that while any arc of the parallel C on the sphere has the cosine of its latitude for radius, the corresponding arc of the cone developed will have the side of that cone for radius. Now, the side of the cone has been shown to be the co-tangent of the latitude of C. Hence, if we suppose the map to contain forty degrees of longitude, the angle corresponding on a plane surface to that number of degrees, in the parallel of 50°, will be as the co-tangent of 50° is to the cosine of 50°; or, what is the same thing, as 1 (radius) : ·766 (sine of 50°) : : 40° : 30° 38′ 24″, the angle required.

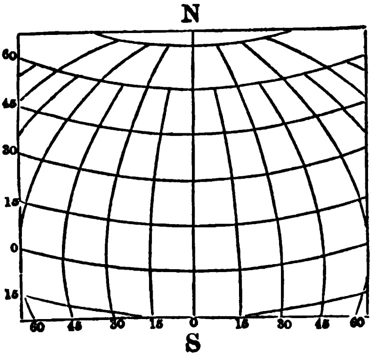
Set off half this angle on each side of O B, and draw O D and O E for the extreme meridians, they will intersect the indefinite arc in d and e, the space between which will represent, or be the development of the forty degrees of longitude required for the map. Next divide C d and C e each into two parts, the spaces thus obtained will be ten degrees of longitude each; through them draw the other meridians O F and O G. Finally, from O describe arcs, concentric with d e, through the several points marked off at 60, 40, &c. on the central meridian; then will the space contained between the extreme meridians and parallels be the conic projection or development of a corresponding portion of the spherical zone, comprised between the latitudes of thirty and seventy, and embracing forty degrees of longitude, and this development will be a correct representation of the corresponding spherical surface, except in as much as the parallels above and below the central one will be a little too large.

A simpler mode of drawing the meridians is to take from a table the number of miles contained in one degree of longitude at the mean parallel, (or find it by the rule—radius is to cosine of latitude as 60 is to *x*,) and ten times this (taken from the scale which served to determine the degrees of latitude on the central meridian), set off twice on each side of C on the indefinite arc, will give the points through which to draw the meridians O F, O G, O D, and O E.

In order to find the side of an *inscribed* cone, as at fig. 12, say—As 57·295 (the degrees of the equator contained in the radius of the sphere) is to the co-tangent of the central latitude, so is the cosine of the arc contained between the central latitude and either of the parallels through which the cone is to pass, to *x*. This distance from the middle parallel, measured on the central meridian produced, will give the apex of the cone, from which to strike the curves representing the parallels.

With a view to obviate the errors in distance, measured on the outer parallels as above alluded to, Murdoch proposed, besides the inscribed cone already mentioned, other methods of conic projection. Euler, also, and others, have entered into profound researches, and given directions for different modifications of the projection we are now considering; but as they only deprive it of its simplicity, without effectually correcting its errors, we shall not describe them, still less the method of Ptolemy which resembles the conic projection. There is, however, one modification of Ptolemy's method, due originally to Flamstead, but subsequently improved, which, being still employed, deserves notice. It consists in the substitution of curves for the straight lines representing the meridians, and is thus effected:—

Fig. 14



Having drawn, as before explained, a vertical meridian N S, (fig. 14,) and described the central parallel with a radius equal to the co-tangent of the latitude of that parallel, and also described the several other parallels as concentric arcs, passing through their proper points on the central meridian, mark off (as many times as is necessary for the longitudinal extent of the map) on each side of this meridian, and on every parallel, the length of ten or fifteen degrees of longitude, according to the law of their respective decrease, which for each parallel is as the cosine of the latitude to the radius. Then through these points describe curves for the several meridians. In our figure, the parallels and meridians are drawn at fifteen degrees apart, and the areas on the globe are represented by equal areas on the projection, but as the forms are dilated in proportion as they recede from the centre, distances can only be measured along the parallels or the meridians. This defect is still further increased by the little attention paid by the generality of map-makers to the point from which they describe their parallels, which, instead of being at the distance of the co-tangent of the central latitude, is determined by the convergence of any two meridians, arbitrarily taken. The distortion that results is particularly seen in the ordinary maps of Asia.

The next and last projection we shall describe is—

The Cylindrical, or Mercator's Projection.—This projection being destined solely for the use of mariners, and having comparatively little interest in a geographical point of view, might be altogether omitted in our present enumeration, were it not that every atlas contains it, and that many persons consult it in preference to the planispheres, when they would have a more satisfactory idea of the relative bearings of those parts of the globe whose contiguity is so awkwardly interrupted by the diverging circumferences of the two hemispheres.

The cylindrical projection was introduced by Mercator, whose name it bears, in 1556. In order to understand the necessity which existed for a projection differing entirely from any of the preceding, it must be remembered that navigators require charts by which they may direct their course, and lay it down with facility. So long as they have to sail due north or south, east or west, the ordinary projections might answer their purpose, but this is no longer the case when the place for which they have to steer lies between the cardinal points. If a vessel starting from any point of the equator, for instance, were to steer a direct N.E. course, such vessel, if land did not intervene, would describe a spiral round the northern hemisphere, and arrive ultimately at the Pole.* This curve is called the *Loxodromic* line. The way in which it is engendered is this. The meridians all run due

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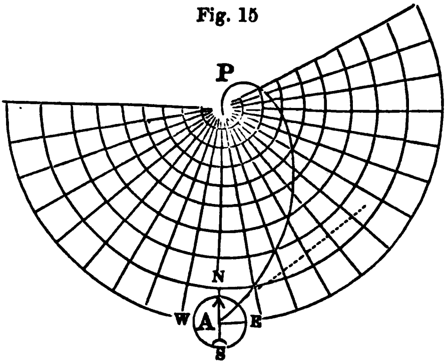
* Mathematically speaking, it could never reach the pole, as for this, it must steer due north.

N. and S., the parallels E. and W., these circles cutting each other at right angles; but while the parallels, as their very name implies, are everywhere at equal distances from each other, the meridians approach nearer and nearer the higher the latitude. Now, as a vessel steering constantly N.E. must move along everywhere by a line 45° from the meridian, and as the direction of every meridian differs, so the vessel's course, after first starting from the equator, will describe the spiral, or loxodromic, curve, and this will be the case on whatever *rhumb* the vessel may steer, for she will always have to intersect the meridians under the same angle, which she can only do by describing the curve. Were she to proceed in a straight line, she would cut every meridian she passed under a different angle, and, consequently, never make the port for which she was bound.

Fig. 15



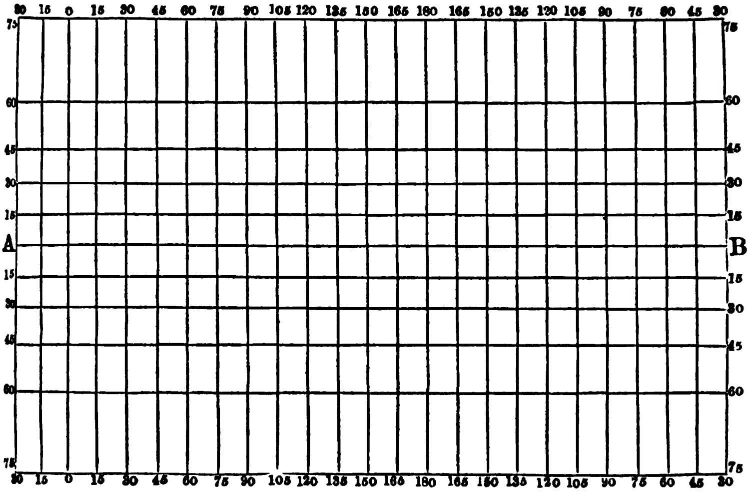
To render this sensible, fig. 15 represents a portion of the sphere projected stereographically on the plane of the equator, in which P is the pole. Now it is evident that if a vessel start from the point A, and steer constantly in a N.E. direction by compass, her course must constantly form an angle of 45° with the meridian; but as every meridian forms an angle with the one just passed, so, in order to form with them successively the same angle, the vessel must in fact change her direction every instant, and describe a curve. If she were to proceed on a straight line, she would make with every meridian successively a greater angle than 45°, till at length she would find herself at some place due east of that from which she set out; to effect which, however, she would have to change her compass-bearing every moment.

For the facility, therefore, of determining and laying down his course, the mariner required such a projection as would enable him, while steering by his compass, to deal with straight lines only on his maps, and accordingly Mercator, who had before introduced the stereographic projection, invented the cylindrical, as we shall now describe it.

Let us suppose a cylinder to circumscribe a sphere in such manner that the axis of the two shall exactly coincide, and the cylinder be in contact with the equator. If now the planes of the parallels be extended beyond the surface of the sphere till they meet that of the cylinder, their intersections with it will form a series of circles parallel to each other and to the base of the cylinder: and if, in like manner, the planes of the meridians be extended till they intersect the cylinder from top to bottom, the intersections will be straight lines equidistant from each other. If, next, the cylinder be slit open in the direction of one of the meridians and laid out flat, it will represent a cylindrical projection of the globe, in which all the parallels will be straight lines, and the meridians also straight lines perpendicular to the former. But while the distances of the parallels from the equator would be the sines of the latitudes, and accordingly so much the nearer to each other as they approached the poles, the meridians would be everywhere equidistant; that is to say, the relation of the parallels and meridians would be the very reverse of what is required in order that the proper relative proportion between them be preserved. For as the length of the degrees of longitude diminish as the parallels approach the poles, whereas, on this projection, this length is made equal on all the parallels, it becomes necessary to *lengthen* the degrees of latitude on the projection in the same proportion as the degrees of longitude really diminish on the sphere, to effect which is extremely easy in practice.

A line A B, (fig. 16,) is drawn of the length required for the development of the equator, according to the intended dimensions of the map. This line being now divided into 36 or 24 equal parts, for as many meridians at 10° or 15° apart, (in our figure we have taken 15° in order to have fewer lines,) draw the meridians perpendicular to A B. Now take from a table of meridional parts the requisite distances of the several parallels and of the tropical and polar circles from the equator, and set them all off on the outer meridians to the N. and S. of the equator; join these points and the lines are all projected. Nothing now remains but to select the first meridian according to circumstances, and then to graduate the top and bottom borders of the map in the usual way, E. and W. from the first meridian, and to indicate the degrees of latitude N. and S. of the equator upon the two extreme meridians.

Fig. 16



The meridional parts in the table just alluded to, (and which is also called a table of increasing latitudes,) are the number of minutes of a degree of longitude at the equator comprised between that great circle and every parallel of latitude up to 89°. It would be foreign to our object to enter here into any detail of the mode of calculating the table.

From the principles of the projection just described, it will be evident that the relations of length and breadth, that is, the figures of the several countries, are perfectly accurate; but that, as the length of the degrees of longitude and those of latitude are greatly exaggerated towards the poles, the relative magnitudes of countries near them, as compared to those near the equator, are grossly incorrect. But this, to the mariner, is of no consequence; his object is to be able to lay down the route he has traversed, in straight lines, and to see the straight-line bearing of the point he is immediately bound for, so as to shape his compass-bearing accordingly, and this the charts on Mercator's projection enable him to do with the greatest ease and most unerring certainty. It is evident that, owing to the inequality of the degrees of latitude and longitude, no *distance* from one place to another can be ascertained but by calculation.

We have stated that a Mercator's projection of the globe is often consulted by the geographer, and we are most desirous, for his purpose, that it be always extended in longitude so as to exhibit *both* the Atlantic and Pacific oceans in their integrity. With this view we would not only carry the longitude 180° east and west of Greenwich, but repeat the last 80° of east longitude on the western side, reckoning back from 180° E. to 100° E. By this means the continuity both of the lands and the oceans would be represented in the most satisfactory manner. Mercator's projection, when designed solely for charts, contains only the details of the coast, islands, soundings, and rhumb lines; but for geographical purposes, they should differ in nothing from other maps, but in the mode of projection.

Having thus explained the nature and construction of the most customary projections, we will merely observe, that there have been proposed and effected several modifications of them; but, generally speaking, if these rectify errors in some particular respect, they increase them in others, or else they offer practical difficulties of execution, which are not compensated by any sufficiently important advantage.

Choice of Projections.—From what has preceded, it will be evident that all the projections are not alike suitable for all purposes. In order to represent the whole surface of the Earth at one view, we must use either the planispheres or Mercator's projections. As regards the former, we have already stated our opinion that the Stereographic projection is the best; though, for our own use, we prefer a Mercator's projection to any map of the two separate hemispheres. When the planispheres are used, the projection is usually made on the plane passing through the twentieth meridian of West longitude from Greenwich, by which arrangement the continuity of the great continents, called the Old and the New Worlds, is uninterrupted. As maps of the world are constructed for the purpose of exhibiting the relative positions of countries, and the bearings of their principal ports and cities, the general forms and extent in longitude and latitude of the grand divisions of the land and of the water, &c., it follows that minute details are not required. Maps of the world, therefore, should contain nothing beyond the contour of the land and water as correctly as possible; the islands with which the ocean is studded, the great streams, the great mountain-chains, the ports and harbours, the capitals and more important towns. Hence it is not necessary that maps of the world should be large; but we shall treat of the scales of maps presently.

In choosing the projections for the maps of the grand divisions of the Earth, and for particular countries, attention must be paid to their form and their extent in latitude and longitude, in order that the defects of the projection may, as much as possible, be thrown into those parts where they will be of the least importance. With this view, the conic projection has been generally chosen, either pure, or in some one of its modified forms, according to the taste or preference of different geographers and map-makers.

Map of Europe.—For Europe, the pure conic projection is unquestionably the best. It is produced by the development of a cone, supposed to intersect the sphere at the latitudes of 45° and 65°, these being intermediate between the mean latitude of Europe, 55°, and the extremes, 35° and 75°. On such a map of Europe, the distances on the two parallels of 45° and 65° are precisely the same as on the sphere, while the deficiency on the intermediate, and the excess on the extreme parallels, being distributed generally over the map, and in themselves very trifling, are of no practical importance. The rectangular spaces on the globe, formed by the intersections of the parallels and meridians, are represented by similar rectangular spaces on the map, and consequently there is no distortion of form. Finally, distances measured in straight lines on the map, very nearly coincide with the shortest distances as measured on the surface of the sphere. No other projection could combine so many advantages, and accordingly we find this projection generally adopted for maps of Europe.

Some geographers may perhaps be content with the development of a *circumscribed* cone, tangent to some parallel near the centre of the map. In this case, we think the best would be that of 50°, by which means the greater correctness would be found in the more important parts of Europe, while the errors in excess would be thrown into the comparatively little important regions of the extreme North on the one hand, and, on the other, over the waters of the Mediterranean and the Black Seas, and the extra European countries, as Asiatic Turkey and a portion of Northern Africa. The central meridian of our maps of Europe generally passes through the twentieth degree of East longitude from Greenwich.

MAP OF ASIA.—The same mode of proceeding, as that we have just described for a map of Europe, may be adopted for one of Asia, making the cone intersect the sphere at the parallels of 25 and 60. It is true, that as Asia embraces a greater extent of latitude than Europe, the errors of deficiency and excess on those parts of the map that are furthest removed from the parallels intersected by the cone, will be somewhat greater than in the map of Europe. But if we exclude the Eastern Archipelago, we find that the extreme South latitude of Asia comprises only the Malayan peninsula, the southern point of Hindostan and the island of Ceylon; while beyond the fifty-fifth parallel of North latitude, there is nothing but the little known frozen steppes of Siberia. We cannot, therefore, see why the pure conic projection, which offers so many advantages, should not be adopted in preference to that distorting modification of it, which we have explained at fig. 14, in which the meridians are projected in curves. It is certain that this method presents upon the map *areas* equal to those on the sphere; but this advantage is counterbalanced by the impossibility of measuring distances except along the parallels and meridians. The custom, however, is to make use of Flamstead's modification. The central meridian for a map of Asia is usually that of 85° East of Greenwich.

MAP OF AFRICA.—The position of Africa, extending, as it does, to nearly forty degrees North, and as many South of the equator, renders it impossible to apply to it, as a whole, any modification of the conic projection. If it were projected on two cones meeting by their bases on the plane of the equator, these cones when developed would present parallels whose curvature would be in opposite directions, those to the North of the equator being concave towards the North pole, and those to the South convex towards that pole; whence it follows that the equator would be represented by two diverging curves, touching only in a point, and the contiguity of the continent consequently broken in a most unseemly and inconvenient manner. Northern and Southern Africa are sometimes given separately, and in such case the conical projection is applicable with advantage. But if, on the one hand, the conic projection be not possible for Africa as a whole, so on the other, if the cylindrical were adopted, it would exhibit all the defects of a Mercator's projection, while its peculiar advantages would have no application. A particular projection therefore, is employed, which so far resembles the Orthographic projection described by us at fig. 2, that all the parallels are straight lines; but while the parallels on the Orthographic projection approximate nearer to each other as they recede from the equator, they are all made equidistant in the projection used for a map of Africa. The meridians are projected in curves passing through points on the parallels determined by the rule of decrease in the degrees of longitude at the different latitudes. The central meridian is at fifteen degrees East of Greenwich.

This projection has been employed by J. B. Nolin for each of the four quarters of the world; its great objection is in the disfigurement of the forms by the obliquity of the meridians in respect to the parallels, particularly towards the extremities of the map, and which renders it impossible to measure distances except along the parallels.

Map of North America.—As this portion of the world, like that of Asia, lies between the fifth and eightieth parallels, the map may be projected exactly like that of Asia, either according to the pure conic, or to Flamstead's modification of it. If the first be chosen, we would say, that upon the principle already alluded to, of throwing the errors into those parts of the map where they will be of the least consequence, it would be advisable to make the cone intersect the sphere at the thirtieth and fifty-fifth parallels instead of the twenty-fifth and sixtieth, and for this reason, that while the greatest amount of error in longitudinal distance would be removed to the barren and little known regions of the North, on the one hand, and to the very narrow portion south of the thirtieth parallel on the other, the distances along the broad and most important part of the region, comprising the whole of the United States, and the settled portions of Canada, would be more correct than if the cone intersected the sphere at parallels more distant from each other. Mr. William Hughes, whom we have great pleasure in mentioning as one of our most scientific geographers, and whose opinion has in general great weight with us, recommends placing the northern entrance of the cone at the sixtieth parallel, but by the adoption, as we recommend, of the fifty-fifth instead of the sixtieth, accuracy is brought still more within the important parts of the map, while the errors in longitudinal distance will still be but trifling at sixty degrees, beyond which, the nature of the country renders the errors in distance of very little moment. Most geographers, however, prefer Flamstead's modification for the map of North America, as for that of Asia. The central meridian for a map of South America is that of 100 degrees West of Greenwich.

Map of South America.—As by far the greater part of this continent lies to the South of the equator, the modified conic projection is sometimes employed for it; but the parallels being very slightly curved, owing to the great length of the radius from which they are drawn, it possesses very little advantage over the straight-line parallels adopted for the map of Africa, and accordingly the latter mode is, by most map-makers, preferred for the map of South America. The central meridian is that of 60° West, and as the land at the southern extremity of the continent extends but a short distance from this central meridian, the distortion arising from the difference in the diagonals of the quadrangular spaces will not be great, nor indeed, if it were, would it be of much importance, considering the little consequence of strictly correct general measurements of Patagonia.

From what has been said, it will be evident that the conic projection can be applied without any material practical disadvantage to the mapping of Europe, Asia, and North America. It is still better adapted to the less extensive regions of the Earth's surface, provided they be not situated immediately on the equator. And, moreover, that whenever the extent in latitude does not exceed thirty or thirty-five degrees, there is very little difference indeed between the distances measured on the map and those on the sphere. For countries on the equator, it is advisable to employ the projection described for the maps of Africa and South America.

In practice it will often be found, that the centre from which the parallels should be described are at such a distance, that it becomes impossible to strike the arcs in the usual way, and accordingly recourse is had to expedients which answer the same purpose, and the details of which will be found in works *ad hoc*.

It is customary with some map-makers to represent the islands of the Pacific on a Mercator's projection, extending to forty or fifty degrees on either side of the equator, and such is the minuteness of these islands generally, that their forms and dimensions cannot be influenced by errors of projection; but their distances and bearings from each other are important, and accordingly we ourselves prefer employing for this great region the projection recommended for the map of Africa.

Different kinds of Maps.—The term *Map* is more particularly applied to representations of the land or land and water together, while that of *Chart* is limited to the water surface only, including indications of currents, soundings, anchorages, rocks, shoals, buoys, lighthouses, and other objects of importance to the mariner, for whose use they are specially designed.

Maps are of two kinds, *Geographical* and *Topographical,* and the former are either *general,* such as the maps of the hemispheres, the four quarters of the world, and the great empires and states, or *particular,* (called also *Chorographical,*) such as the maps of provinces, counties, &c. Topographical maps differ from those called Geographical by their more numerous details. In order that every feature, both natural and artificial, of the surface be represented, the scale of the map must be proportionably large, and hence topographical maps usually embrace a smaller extent of country than geographical maps, though there exist topographical maps of most European kingdoms. Generally, however, they are confined to much smaller surfaces, as counties, parishes, the environs of capitals and large towns, fields of battle, &c. Between the geographical and the topographical map there is an intermediate kind, termed *semi-topographical,* which contains more detail than the geographical, and less than the topographical.

Besides the maps required for pure geography or for topography, there are others constructed for special purposes, involving locality as an essential element. These purposes may be political, civil, military, statistical, ethnographical, historical, physical, &c., and their several subdivisions: in the present work, however, we must confine ourselves to geographical and topographical maps.

As the difference between geographical, chorographical, semi-topographical, and topographical maps, consists not in the size of the maps, but in the amount of detail they represent, so the possible amount of this latter depends entirely upon the scale to which the map is engraved.

On the Continent, it is the custom to state the scale of maps in proportional parts of nature. The scales of general and chorographical maps range from a two-millionth to a two-hundred-thousandth. The first, which is equivalent to about thirty miles to an inch, admits of the insertion of principal mountains, rivers, great towns, and remarkable places. A scale of a two-hundred-thousandth, or about three miles to an inch, admits of the introduction of lesser towns and villages, noted hills, rivers, woods, marshes, main-roads, &c.

Topographical maps range in scale from a one-hundred-thousandth, or 1·5 miles to an inch, to one-ten-thousandth, or six inches to a mile, which is the scale of our Ordnance map of Ireland. This latter scale admits the representation of the minutest details; every accident of the ground, every hamlet, every small stream, every by-path, may be laid down on such a map. Maps upon a larger scale than one-ten-thousandth are rather to be considered as plans.

Whatever be the scale on which a map is engraved, it is generally a reduction from original drawings on a much larger scale: sometimes from regular surveys, laid down on so large a scale that the minutest topographical details are delineated. Maps of little known countries, that have never been regularly surveyed, are either drawn and reduced from the rough sketches of the routes of travellers, and points laid down by them from distances and bearings, or are protracted by the map-maker from the traveller's note-book. Generally speaking, all maps, as they now exist, (of extensive regions,) are the result of a combination of astronomically determined positions, of regular surveys, and of travellers' routes and relations, and they are successively improved as the spread of civilization offers greater facility for the exact determination of positions. When we compare any of our modern maps with those of ancient construction, we are struck with their dissimilarity, and the extraordinary distortion in the shapes of countries as formerly laid down, and we are apt to consider our modern maps as perfect. They certainly come much nearer to the truth than the older maps, and it is perhaps not too much to say, that, omitting the details of certain coasts little frequented, or still unexplored, the coast lines of the globe are pretty correctly mapped as to general outline. In like manner the latitudes and longitudes of all capital towns and ports are, perhaps, as nearly correct as imperfection in instruments will permit. Some few are found to be incorrect owing to the imperfect state of the instruments, otherwise good, with which the observations were taken at the time, and in some cases to want of ability in the observers. Such incorrect positions, however, are becoming every year fewer, as fresh observations are made with improved instruments and greater care; and the time is probably not far distant when every place of note will be set down in its proper position on our maps as nearly as possible. It is, however, far otherwise with the other details of some of the most extensive regions of the earth. Thus, the interior of South America, though, to the eye, well filled in upon the map, offers but a distant approximation to truth; and when, in after years, the axe shall have cleared the secular forests of that portion of the New World, and the vast regions that extend from the Andes to the Atlantic, shall be covered with the abundant harvests and the habitations of a dense population, the maps of the country then constructed will, upon a comparison with those now existing, show our descendants how wide of the truth were our maps in the position of many places, and how totally different the true course of its rivers from what we now figure them with such show of accuracy. In like manner, a great portion of North America, and the whole of the interior of Africa, remain yet untouched by the astronomical observer and the surveyor, and the same may be said of the greater part of Asia. As these several regions become explored by the scientific traveller, the maps of them are improved. The greater part of Europe alone and of the United States may be said to be correctly mapped from trigonometrical surveys. Indeed, if nothing were set down on the maps of other parts of the earth but what has been really determined in a satisfactory manner, the maps of them would present, for the most part, so much blank paper. We have often thought it were greatly to be desired that some enterprising and competent geographer would publish a set of maps in which the really known, the tolerably exact, and the merely presumed, should be distinctly marked; it would prevent the loss of time incurred by going over again what is known, and would point out what yet remains to be done for the exact representation of the earth's surface, and the correct setting down of man's various habitations.

Reduction of Maps in general. — We cannot go into the details of the geodetic operations by which a country is surveyed. This belongs to treatises on geometry and trigonometry; suffice it for us to say, that where the materials exist, topographical maps are reduced from the plans trigonometrically surveyed on the ground. Chorographical maps are produced by the assemblage and reduction of the topographical maps, and geographical, or general maps, from the union and reduction of chorographic, or particular maps, and it is in these reductions from the larger to the smaller scale that the details incompatible with the latter are omitted. We will first state briefly the mode in which these reductions are made, and then pass on to the construction of maps of countries which have not yet been topographically surveyed.

Having the original drawings of a topographical survey, the map to be made from them may either be, as is sometimes required, on the same scale, or on a reduced scale; in the first case, all that is requisite is, to unite the several parts of the survey into a whole, or into sheets, each of which is formed of two or more portions of the actual survey. To effect this, each portion of the survey must have at least two points in common with the portion which is to join it, and these points may be made to coincide, either by joining the two portions of the survey together, or by transporting the points on the clean paper which is to receive the contents of the sheets to which they belong in common. In this latter case, a line must be drawn through the two points, and extending beyond them as far as requisite, and having, in like manner, drawn lines through the two points on each of the original sheets, similar squares or other figures, starting from one of the points in question, must be drawn over the original survey, and over the clean paper to which it is to be transferred. The smaller these squares or other figures are made, the more exact the copy is likely to be. If we would avoid covering the original drawing with lines, a plate of glass, already marked into squares, may be applied to the original, taking care that the squares on the clean paper correspond exactly with them. All that is now to be done, is to copy each square successively by the eye. Essential points, however, should be transported by compass measurements. These operations must be continued till the whole is completed, taking especial care, as we have said, that there be always two points on each separate portion which correspond, or are repeated, on the separate portions contiguous to it.

When a reduction is required, it is very simply effected by making the squares or figures to be filled up on the paper, though they must always be the same in number and disposition, smaller in proportion to the extent of reduction required, remembering that the reduction of the surface is inversely as the square of the linear reduction. Thus, if the sides of the reduced quadrilateral figures are half the length of those on the original drawing, the surface of each square will be the quarter of the original. If the sides of the reduced squares are one-third, the surface will be one-ninth, and so on.

In France the separate portions of a survey are at once transferred upon the copper in the manner we have described, both when the scale of the engraved map and that of the original drawing are the same, and when there is reduction.

It does not always follow that, because the scale is reduced, any of the details of the original survey should be omitted; for the reduced scale may still be such as to admit of their distinct representation. Sometimes it is necessary to increase the scale of a map: but this is always attended, more or less, with the disadvantage of magnifying any errors that may exist, whereas the contrary operation of reduction diminishes, and sometimes wholly obliterates them.

Of Topographical Maps in particular.—The great advantage of topographical maps consists in the numerous details they supply; and, above all, in presenting the *relief* of the surface; that is, the heights and depressions so necessary to be known for all engineering and military purposes. A very great deal might be written on the modes of representing the mountains, the hills, and all the minor undulations of the ground on the flat surface of a map, but our space will not allow us to go fully into this subject. Various modes of drawing and engraving the hills have been, and still are adopted; but they may be classed under two principal heads. In the one, all that is aimed at is picturesque effect; in the other, a greater or less amount of mathematical precision has been *attempted*. In both, the disposition of light and shade is the mode by which effect is produced; but while, in the one case, the proportion of this light and shade has no other rule than the caprice or taste of the draftsman and engraver, in the other it is systematically regulated. In both the arbitrary and the systematic modes, the light is sometimes regarded as falling obliquely, and sometimes as falling perpendicularly. The following tabular view will, however, best convey an idea of the various modes adopted:—

Arbitrary.	Etched lines alone, these being . . .	Arbitrary in direction. " " in length. " " in thickness, and " " in distance apart. The light falling at an angle of 45°.	1.
Systematic and Arbitrary.	Etched lines alone, these being . . .	Systematic in direction; being the projections of the curves of greatest slope. Arbitrary in all else. The light falling at an angle of 45°.	2.
	Contour lines and etched lines employed together. This mode is . .	Systematic in the contour lines, which are at equal altitudes, but the altitudes varying according to the scale of the map and the nature of the country. Arbitrary in the etched lines in everything but their length, which is limited by the contour lines, between which they are drawn. The light falling at an angle of 45°.	3.
Systematic.	Contour lines alone .	Systematic, as in No. 3, the lines being drawn at equal altitudes, but which vary according to the scale of the map and the nature of the country.	4.
	Contour lines and etched lines employed together .	The contour lines as above. Etched lines. 1. Direction. Length. } determined. Thickness equal. Spaces one quarter the co-tangent of slope. No regard to light.	5.
		Etched lines. 2. Direction. Length. } determined. Thickness proportional to the sine of angle of slope. Spaces as the cosines. Light vertical.	6.
	Etched lines alone .	Determined in direction, length, thickness, and spaces.	7.

Besides the above seven modes there are several others, but which must be all classed under the arbitrary, except one, which is mechanical, and of which we shall say a word presently. In some of these the effect is produced by aquatinta shading, in others by stippling. In some maps the hills are represented in perspective; in some the shading is effected by etched lines, straight and waved, and dots, and all other modes which the engraver can devise to produce effect.

Of the several systems above mentioned, we may observe that, where picturesque effect is all that is wanted, the arbitrary modes are superior to the systematic; indeed, some maps executed according to this arbitrary method, represent, in the most striking and satisfactory manner, every undulation of the soil, from the gentlest rise to the highest and most abrupt eminences. They accordingly give a very perfect idea of the country, but are of no use for the exact purposes of the engineer, or for the operations of an army. This is easily conceived. The engineer who has to construct a canal, a railway, or any other kind of road, to form reservoirs, to drain marshes, &c., can be satisfied with nothing less than positive levels, and these the arbitrary modes of drawing hills, however effective they may be, do not supply. In like manner, the general must be able to see upon his map where artillery and other wheel carriages can pass, where his cavalry can act, and where none but his light infantry can advance; what heights command or are commanded, &c.; he therefore, like the engineer, must know the positive amount of the slopes, and must accordingly discard the more beautiful, though to him useless topographical maps, for those where he sees the actual slope and elevation of every foot of the ground.

As an example of arbitrary shading, we may mention the Ordnance map of England, which can be seen at any time. In this topographical map the effect is produced by etched lines; the light is supposed to fall upon the ground under an angle of 45 degrees, and on the map to come from the left hand upper corner; the shading is regulated accordingly, the greatest depth being given to the loftier and steeper eminences. Another and very beautiful example of arbitrary shading may be seen in the semi-topographical map of Sardinia, lately executed by General Marmora. In both these examples the shading is by etched lines. A map of very excellent effect as regards the hills, and which I shall have occasion to mention for another reason, has lately been executed at Vienna; in it the hills are in imitation of stippling, and the effect is truly excellent.

Of the systematic modes, we shall mention only numbers 4, 5, and 7, of our table; and first, of the method by contour lines alone, or the representation of the elevations of the surface by curves of equal altitude. This method, admitting of a very near approach to geometric accuracy, has for engineering purposes a decided advantage over every other, though in some respects it is not without its inconveniences. As it has been much talked about lately, and is again coming into use, its history, and some details respecting it, may not be unacceptable to the reader.

The first idea of the contour system is attributed by some to Philip Buache, but by La Croix to M. Ducarla, who, he says, considering that if a line were drawn joining all those points on a chart which are marked as having the same depths of water, the contour thus traced would be that of a section cut off by a horizontal plane everywhere distant from the surface of the water by so many fathoms, or feet, as are marked by the soundings—conceived a means equally ingenious and satisfactory of geometrically representing the elevations of the ground, or the *relief* of a country. We shall occasionally employ this term *relief*, because it is both laconic and appropriate, and because we have no other single word, as far as I know, that answers so well. Whether it be to Buache or Ducarla that we are indebted for the first idea of the contour system, it was first published by M. Dupin Triel, in 1784. It consists in projecting vertically upon the plane of the horizon, lines passing through points equally raised above the level of the sea; lines, in fact, which would mark the limits of the ocean, if, by any cause, it should rise to the several heights indicated, in the same way as the lines joining equal soundings would become its successive limits if it were to sink to the depths of those soundings.

The imaginary horizontal planes whose intersection with the elevations of the ground form the curves projected on the map, rise one above the other by equal quantities; the actual amount of the rise, however, depends upon both the nature of the ground and the scale of the map. It is indeed self-evident, upon a little consideration, that in the case of very gently sloping ground, if the altitude of the section be considerable, the curves must necessarily be very far apart from each other, whereas in elevations nearly perpendicular, the projection of sections taken at the same height, one above the other, would almost touch: those of a vertical cliff will in all cases coincide and form but one curve. Accordingly it is found convenient to increase the vertical height of the sections as the hills are more steep, and to diminish it as the ground is more gently undulating.

The necessity of varying the heights according to the scale of the map is evident for a similar reason. For, if while the height of the sections remained the same, the horizontal scale were enlarged or contracted, the same inconvenience would be produced. The vertical distances of the horizontal sections depend also upon the particular purpose for which the map is intended. Thus, while on the plans intended for certain engineering works, the sections may be from two to four or five feet of vertical altitude, in topographical maps they may be much greater. The pure contour system may even be used in general maps, but then the vertical heights are necessarily very considerable. In Dupin Triel's map of France, on a scale of about one-two-millionth, the first sections, beginning with the sea-level on the coast, rise by ten toises each, where the ground is nearly flat; further inland, where it rises more rapidly, the curves indicate sections taken at twenty toises, then at fifty, then at one hundred. The first are observed in the north-western portion of the country, and the latter in the southern and south-eastern, where the more rapid slopes of the Pyrenees and Jura occur. It is evident that whatever be the scale of the map, contour lines alone cannot convey that expression of relief that results from shading, unless they be exceedingly numerous and close. On a scale of one-ten-thousandth, or about 6⅓ inches to a mile, the relief may be satisfactorily figured by contour lines alone. We do not, however, recommend their adoption where effect is to be studied, they should be reserved for those purposes that require exact levels, as for draining, canal and road making, the *défilement* of fortifications, &c., and in these cases the distances of the curves from each other are much too considerable to picture relief. On the Ordnance Survey the contours lately introduced represent sections taken at the altitude of twenty-five feet.

When contour lines are drawn upon chorographical maps, it is evident the sections have not been levelled, that is to say, the horizontal planes of equal altitude have not been determined by the usual process employed for small distances. The curves are drawn through points whose altitude has been ascertained by barometrical or trigonometrical means, and the sections are not flat parallel planes, but portions of concentric spheres, whose surfaces are parallel with the convex surface of the ocean. It is much to be regretted that curves of equal altitude, such as those on Dupin Triel's map of France, are not more generally applied; they would throw great light on a vast number of some of the most interesting problems of physical geography. We have a map of Ireland, on the scale of ten miles to an inch, on which five successive curves are drawn at the heights of 250, 500, 1000, and 2000 feet, and the belts between these curves being tinted, produce a very effective picture of the positive and relative elevations of different parts of the country. A map of Hong-Kong has also been contoured in a very successful manner, the scale being four inches to a mile, and the section one hundred feet vertical. Indeed, the system we are considering is admirably appropriated for islands, particularly when they are small, for the whole coast-line forms a closed curve, giving the lowest horizontal plane, or starting point, in all directions; whereas in sectional maps, that is, maps of a portion of country, the rectangular edges of the map intersect many of the curves. This inconvenience is in part obviated by the addition of numbers to the curves; the same numbers denoting, of course, the same levels.

Closed curves may represent depressions, as well as elevations, and this is one of the disadvantages of the system; but if the curves are numbered, a little attention will suffice for determining whether the closed curves belong to elevations or depressions. If the number on the innermost or smallest curve be *greater* than that of the curve next to it, the curves are those of an elevation; but if, on the contrary, the number on the innermost curve be *smaller* than that of the curve next to it, the curves are those of a depression. Captain Vetch, of the Royal Engineers, has proposed to add to the contour lines, short etched lines on the side on which the ground falls, which effectually prevents all ambiguity on the subject.

Upon the whole, then, the system of contour lines alone is by no means to be recommended as a means of representing pictorially the inequalities or the relief of the surface on maps; but when positive levels are required, we know of no mode possessing equal advantages. It does not therefore belong to maps constructed for general geographical purposes, but to maps designed for special objects. We now pass on to the consideration of the fifth system of our table.

The French, who attach much higher importance than we do to correct representation of the inequalities of the surface in topographical maps, have at various times considered the subject in committees called together by the Government, and composed of the heads of all those scientific departments for whose purposes good maps are essential, such as the etat-major, the corps of engineers, civil and military, the mining department, the woods and forests, the department of bridges and highways, and the heads of the several great schools, such as the Ecole d'Application of the Geographical Engineers, the School of the Etat-Major, that of the Mining Corps, that of St. Cyr, &c. These committees have on some occasions sat for three or four years, going most minutely into every detail of the subject, and having the same portions of ground drawn and engraved upon a variety of scales, and according to every variety of mode.

We cannot, of course, enumerate all the opinions that were emitted by these most competent persons, of the respective advantages and disadvantages of the several systems, and their numerous modifications; suffice it in this place to say, that no system has yet been devised that is wholly unobjectionable; that, however, which was at length adopted by the majority, and which is at this moment sanctioned by the Government, is that which bears the number 5 of our list.

This system is calculated to offer, as far as possible, the double advantage of geometrical accuracy and picturesque effect. It is a combination of the contour lines with the *hachures* or etched lines, these latter producing the requisite tints of shade, which convey to the eye the effect of relief, and that with so much truer effect, as this very shading is subject to rule, and is determined in strict relation to the contour lines themselves. These latter being determined and drawn upon the map, the space between them is filled up with etched lines, whose length is determined by the distance between two contiguous contours, while their direction is perpendicular to the contour lines; they are accordingly the projections of the lines of greatest slope, of those, in fact, which water, acted upon by gravity alone, would follow in running down the surface. The thickness of these lines is not determined by any rule in the system we are now considering; but whatever it may be, it is uniform throughout, the tint of the shading being effected by the greater or less distance left between the strokes, and this is (except in the extreme cases we shall presently notice) invariably one-fourth of the distance of the two contiguous contour lines, between which they are drawn. When the vertical heights of the horizontal sections whose projections form the contour lines of the map are equal, it is evident that the contour lines will approximate so much the closer as the slope of the ground is the more rapid; and as the distance between the strokes is regulated by that of the contour lines, it is clear that the nearer the contour lines, the closer will be the *hachures* (etched lines, or strokes of shading) to each other, and consequently the darker the tint or shade produced by their means. Therefore, the steeper the slope, the darker the shading, and that without any direct reference to the way, either slanting or vertical, in which the light is supposed to fall. When the contour lines are distant from each other, the strokes of shading, being always one-fourth of the distance between the contour lines, will also be far apart, which of course produces a very faint tint, such as is required for the representation of a very gentle slope.

We have stated that, in extreme cases, the rule of one fourth of the distance of the contour lines is not observed, and for obvious reasons. So long as the contours run in straight, or nearly straight lines, the strokes which are perpendicular to one of them will also be perpendicular to the contiguous one, and the distance of one stroke from another will be everywhere the same. But when the contour lines form curves, the distance of one fourth being taken on the upper line, and the strokes drawn perpendicular to it, these strokes naturally diverge as they descend, so that at their contact with the next curve their distance is greater. If the distance between these curved contours be not great, the divergence of the strokes of shading is of little consequence; but if the contours are wide apart, and the strokes therefore long, the divergence becomes an object worthy of attention; and accordingly, in such case, the distance of one fourth is taken, not upon the contour lines themselves, but on one drawn for the purpose midway between the two, so that the strokes are brought closer together, and the inconvenience of excessive divergence is remedied.

The other extreme case is the opposite of the one just explained—namely, when two consecutive contours approach nearer than two millimetres, (about the ·08 of an English inch). In this case, as it would be next to impossible to draw four strokes of shading in so small a distance, the law of one fourth gives place to an increased thickness in the strokes themselves, by which the very dark tint required for the shade of such rapid slopes as the contiguity of the contours indicates, is equally well effected.

Such, then, is an idea of the fifth system on our list, and which is that generally adopted in France, and also in the United States, where they have learnt it from the French; and some of the topographical maps lately executed at New York, according to this system, are extremely beautiful. The sixth system of our table, which is that advocated by Colonel Bonne, was sanctioned by the French government, in 1828, for the Dépôt de la Guerre, more especially for such maps as were to be engraved. It differs from the fifth, but they both combine the two great requisites of geometrical accuracy and picturesque effect. The contours being preserved, are easily traceable by breaks in the continuity of the shading strokes or etched lines; every gradation of level is marked for engineering and military purposes, while the shading figures at once the undulations of the surface and points out the several degrees of inclination of all the slopes of the ground. Let us now pass on to the seventh system of our list.

In Germany and some other countries, the mode of representing the inequalities of the surface in topographical maps, differs essentially from the French systems we have just noticed. That generally adopted, though slightly modified in different places, is known as Lehmann's, or the Saxon method. In it there are no contour lines; the slopes or inequalities of the surface are represented by etched lines, or *hachures*, alone, but then the thickness of these, and their distances apart, are regulated according to scale, so that a determined proportion is maintained between the rapidity of the slopes and the intensity of the shading by which they are represented. The direction of the strokes is that of the greatest slope; their thickness and distance apart is determined as follows:—

The light is conceived as falling vertically upon the ground, and, accordingly, the different parts of the surface will be more or less illumined as they are more or less inclined to the supposed vertical rays of the sun. A horizontal surface receiving the full effect of these rays, will, in nature, be the lightest, and is therefore represented on the map without any shading; while a highly inclined cliff, receiving few of the vertical rays, will be very dark in nature, and is accordingly represented by a very dark shading on the map. To determine a regular gradation, however, between the most and the least illumined surfaces, the following system was determined on.

The angle of 45° was regarded as the greatest natural slope of the ground, and this was supposed unillumined. From this inclination down to the horizontal, all intermediate slopes were supposed to be illumined inversely as the angles of elevation, and hence the angle of any slope less than 45°, and its supplement, or what it wants of that number, were considered as the proportional terms of light and shade on any declivity. Thus the proportion of light and shade on a declivity of 5° was said to be as 40 to 5, or 8 to 1;—on a declivity of 10° as 35 to 10, or 3½ to 1;—on a declivity of 15°, as 30 to 15, or 2 to 1, &c. These suppositions,—viz., that a slope of 45° is the greatest natural slope of the ground—that such a slope receives no vertical light—and that the quantity of light received by all slopes of less inclination than 45° is in proportion to such inclination, are perfectly gratuitous, the facts being—1. That 60 is the greatest natural slope of the soil;—2. That a slope of 45° receives a very considerable quantity of vertical light; and—3. That the amount of vertical light received by any slope whatever is exactly in proportion to the cosine of the angle of such slope. Hence it is clear, that though the

Saxon method of representing the relief of the ground be systematic, it is by no means natural: it is, in fact, a conventional system, whose practical execution is thus effected:—

All slopes of 45° and upwards are represented on the map by absolute black. All slopes below this, down to the horizontal, are represented by graduated tints of shade growing lighter as the declivity is less, till, at the horizontal, the paper is left perfectly white. As it would be impossible to represent every minute difference of inclination from 45° to horizontality, or to pass from absolute black to perfect white, so that the eye could at once detect the difference between contiguous shades, the tint is effected by nine different grades of shading, each indicating a difference of 5° in the slope. The mechanical means employed to produce these nine different tints is by *hachures* drawn in the direction of the greatest slope, and the thickness of these *hachures*, or etched lines, bears the same proportion to the white space left between them that the angle of the slope to be represented bears to what it wants of 45°. Thus—

Angles		Hor.	5°	10°	15°	20°	25°	30°	35°	40°	45°
Proportion of	Black	0	1	2	3	4	5	6	7	8	9
	White	9	8	7	6	5	4	3	2	1	0

If the slope to be represented be one of 30°, its complement, or what it wants of 45°, is 15°, which being the half of 30°, the black lines will be twice as thick as the white spaces left between them, and as 45° is represented by perfect blackness, and from this to perfect whiteness is divided into nine grades of shades, it is clear, each of these grades becomes lighter than the other by one ninth; 45° having the whole nine parts black, 40° will have eight black and one white—35° will have seven black and two white—30°, six black and three white, and so on, as in the above table; whence it is seen that, while the shading for a slope of 30° is produced by *hachures* whose thickness is to the space between them as 6 to 3, or 2 to 1, that of a slope of 15° is produced by *hachures* whose thickness is to the white space between them as 3 to 6, or as 1 to 2. The tints thus become successively lighter as the rapidity of the slope diminishes, and although the progression is not a natural one, it is invariably determined by a conventional scale, so that, if strictly adhered to in practice, not only the relative steepness of the hills is picturesquely represented so as to produce the sentiment of relief, but the positive amount of the inclination is shown; and further, as the length of the slopes on the maps is the horizontal projection of such slopes, it is evident that this, the Saxon, or Lehmann, system, supplies the means of obtaining as correct a profile of the ground as the contour system of the French. Unfortunately, however, the practice of this method does not answer to the theory. In the first place, it is exceedingly difficult in execution. No draftsman, whatever skill he may have acquired, or however careful he may be, can keep strictly to the thickness of the strokes, and to the distance between them, required by the scale, and without the most perfect accuracy in this respect, the system loses its chief advantage. The labour of drawing such myriads of small strokes fatigues the eye, and diminishes its faculty of discriminating the thickness of the strokes and the breadth of the spaces between them; the hand becomes unsteady, the pen wears thicker, the ink evaporates while you are working, and thus, insensibly, you are drawing a slope of 5°, 10°, or 15° greater steepness than you should do; and even supposing the most favourable case of very exact and clever draftsmen, there is seldom uniformity between the several parts of the same map when executed by different persons; the engraver also may falsify the whole; and if we add, that when the slopes are not taken in the field with instruments, but merely by the eye, they cannot be mathematically correct, and that, accordingly, a profile drawn from the map, may give heights very different from what they are in nature—it will be evident that the German method, though ingenious, though systematic and beautiful when carefully executed, is liable to so many defects in practice, as still to leave room for something more perfect, more easy of application, less tedious, less expensive, and more readily understood by the public at large, for whom, after all, maps are made. Various modifications of the method just described have been attempted, but with little success. To detail them, and a variety of other systems, would require a great deal more space than we can devote to the subject. Nevertheless, we must say one word on anaglyptography as applied to maps. The perfect resemblance of relief which is obtained by this art, is well known in the case of medals and coins. But the first idea of its application to the purposes of geography seems due to Mr. Greenough.

At a meeting of the British Association at Bristol, in 1836, that gentleman expressed, in the Geological Section, a hope that the process in question might be applied to the delineation of mountains; and at the meeting of the same body at Liverpool, in the following year, Mr. Dawson, one of the ablest draftsmen employed in the ordnance survey, having acted on Mr. Greenough's suggestion, exhibited a small map produced by the anaglyptographic process, and representing a portion of Wales. Subsequently, a much more perfect specimen was executed by the direction, we believe, of Colonel Colby. Mr. Lowry (the father) executed for Professor Phillips a small anaglyptographic map of the Isle of Wight, and other maps have since been done, particularly one of a portion of the Pyrenees in four sheets. In producing the appearance of relief, nothing can equal the process we are speaking of; but there are two circumstances which will ever prevent its application to maps becoming general. In the first place, a correct model of the country must be first produced, for it is by applying the instrument to a model that the engraving is produced. Now, it is at once evident that the expense and time required for modelling, not only a whole country, but any large district, must ever preclude the application of the anaglyptographic process for maps of such extensive surfaces. Secondly, the very perfection, strange to say, of the effect produced is against its use for maps. It is well known, that if an intaglio receives the light from the left, it has the appearance of a relievo lighted from the right, and, in like manner, a relievo, in certain circumstances, assumes the appearance of an intaglio. Now, the anaglyptographic process gives so true and beautiful an effect of relief, that it is sometimes necessary to pass the hand over the surface, in order to be convinced that it is flat. But from this very perfection it follows that, unless the light fall upon the map in a manner conformable to the shading of the map, all the hollows become reliefs, and the reliefs hollows; so that, seen in certain positions, the valleys assume the appearance of sharp ridged chains, with all the rivers and streams running along their summits. This very remarkable effect is most striking in the anaglyptographic map of the Pyrenees. Such maps, therefore, have the great inconvenience, that they can only be looked at in one direction as regards the light, and when they are to be suspended, they can be so, only on one particular side of the room as regards the light. In some cases, we believe, maps executed by this process have had engraved upon them, directions as to the way of looking at them. These, then, are inconveniences which cannot be got over, and accordingly the mode of engraving we are considering will never become general, and need not therefore engage us any longer.

We cannot here go further into this subject, nor is it necessary in a strictly geographical point of view that we should; for whatever be the system employed for representing the relief of the ground, and whatever interesting details topographical maps may exhibit, they must all be rejected when these maps are reduced for the construction of geographical maps. Some few of the principal features, such as the most prominent elevations of the ground, the high roads, &c., are retained in what are termed the semi-topographical maps, which hold a middle position between the topographical and the geographical map. The former also contains all the smaller towns, and even the villages, which, in geographical maps, cannot be set down, by means of the smallness of the scale.

Maps are constructed in an order the reverse of their details. Thus, a topographical or a semi-topographical map is a reduction from the actual survey; a chorographical map is a reduction and assemblage of topographical maps, and a geographical map, a reduction and assemblage of chorographical maps, and all details which a diminished scale renders too minute to be easily appreciable or correctly expressed, are necessarily omitted.

OF CHOROGRAPHICAL MAPS.—We have already explained the process for assembling and reducing the several portions of a survey, to form from them a topographical map, but when we would assemble and reduce these latter, in order to construct a chorographical map, we have, moreover, to subject the operation to the projection we adopt. For this purpose; having projected the permanent parallels and meridians of the intended map, and traced as many intermediate ones as may be deemed necessary, draw upon the topographical maps, and in their true direction as regards the north, straight parallels and meridians perpendicular to each other, and corresponding with those of the projection; then copy what is contained in the squares of the topographical map into the corresponding quadrilateral spaces of the projection. As the squares of the one do not exactly correspond with the quadrilateral spaces of the other, we must, if great accuracy be required, ascertain the distance of the point to be set down, from the sides of the square within which it is placed in parts of a degree of latitude and longitude, and then take similar parts from the parallels and meridians on the projection.

OF GEOGRAPHICAL MAPS.—The passage from the chorographical map to the geographical, is similar to that just described for the construction of the former. It must be observed, however, that as errors may have been committed either in the original topographical maps, or in the reduction of these to form a general map; it is advisable to check such errors by marking at once on the projection, whether it be for a chorographical or a geographical map, a certain number of important points in their true astronomically determined positions, so that if the intermediate spaces and objects as they exist on the maps to be reduced and copied, are either too proximate or too remote, the distances may be extended or shortened, so as to bring them to their proper limits, and by spreading the errors over the whole surface, diminish their individual importance. There are different ways of effecting this correction, but we are compelled to refer for such details to works treating expressly on the practice of map-making.

What has just been said applies only to maps of such countries as have been trigonometrically surveyed; but as this is the case for a very small portion of the Earth's surface, other means must be resorted to when regions less perfectly known are to be mapped.

CONSTRUCTION OF MAPS FROM VARIOUS MATERIALS.—It is in the construction of maps from a variety of different materials, all more or less imperfect, that the talent, the knowledge, and the critical acumen of the map-maker are most conspicuous. We use the term map-maker, instead of that of geographer, advisedly; for in our estimation they are by no means synonymous. The geographer is not merely conversant with the positive and relative positions of the several objects on, and features of, the Earth's surface, but he is also acquainted with the particular character of the several regions of the globe, as regards climate and productions; he understands the physical laws by which the several phenomena are regulated, and the influence of the soil and aspect in modifying the meteorological action, &c. Now, the mere map-maker has no such knowledge, nor is it perhaps, strictly speaking, absolutely necessary that he should possess it, not but what it would be all the better, nay, infinitely better, if he did. We could, it is true, name one or two, who, in addition to the practical knowledge they possess of map-making, add an extensive acquaintance with all that a geographer should know, but they form the exception, not the rule: nor do we make the observation in disparagement of the talented and conscientious map-maker; his merit is great, his duty arduous, and, if well performed, he is justly entitled to the best thanks, not only of the public, but of the geographer himself, for whose studies he supplies indispensable materials. Alas! that there should be so few, so very few good map-makers. Of all those who supply the public and cater to their appetite for maps, how many are there who produce anything of their own? Not one in ten—not one in fifty. Nor is this all. Not content with embodying in their productions the labours of others, (a plagiarism, by the way, tolerated by usage, and without which we should have but three or four names to all our modern maps,) they do not even copy correctly. Indeed, the carelessness, not to say the want of common honesty, with which some maps are got up and sent out among the public, is a crying evil; but—and we regret to say it—so small is the amount of knowledge possessed by people in general of this department of science, that if not one map in ten be good for anything, there is not one person in a thousand capable of detecting the errors, or discovering the discrepancies of the maps they purchase. If there were sound critics in this matter, map-makers would perhaps be more careful, and find it better for their reputation, if not more to their interest, to publish less in quantity and superior in quality. When we shall have explained what is required of a good map-maker, it will soon be seen how far it is possible to believe that anything like care can be bestowed upon those maps which are issued to the public with a kind of railway precipitancy, so soon as any particular interest is attached to any particular region. But to return.

The construction of the map of a country that has never been trigonometrically surveyed, requires the use of a great variety of materials, and a profound knowledge of their respective value. These materials are the existing maps, the positions, as deduced from the use of Ephemerides, the measurements and relations of travellers; and where all these differ, as they invariably do, more or less, much knowledge, much time and labour, and great sagacity are required in arriving at even an approximation to the truth, through such a mass of conflicting documents. Suppose the longitude and latitude of a place to have been determined by eight or ten different persons at different times, and that none agree. It will not do, as is sometimes recommended, and is the almost invariable practice, to take a mean of the several determinations, for this may give a position far wider of the truth than some of those already laid down. If, of the twelve different positions assigned to Mexico within the last century, a mean had been taken between the extremes of longitude, the position, instead of being rectified, would be set down about two hundred miles to the West of its proper place, and further removed from the truth than any one of the twelve positions assigned to it, except two; and a mean of the extreme latitudes would place it further North than any, but one. The same may be said of an infinity of cases, especially of those in which the errors, as is frequently the case, lie all one way. The conscientious map-maker, therefore, will ascertain how the several positions were respectively determined—if astronomically, how, when, and by whom. As to the *how*, some methods give more correct results than others: as to the *when*, what instruments could the observer have had at the time; they may, nay, in most cases, must have been very defective compared with those of the present day: what astronomical tables existed at the time, from which the observers could make their calculations, and how far could these Ephemerides be depended on? As to the observers themselves, were they known as exact and able, or were they persons who, from want of education and capacity, were entitled to no confidence? If the longitudes were determined by the transport of time, what amount of reliance can be placed on the watches then in use? and how far can the place to which the time was referred, be regarded as accurately laid down—or if incorrect, are the amount and direction of the error ascertained? If the positions were determined by itinerary measures, what were they, and is their true value positively known? Sometimes the only measure has been days' journeys on foot, or estimated by the pace of the horse, the camel, &c. Was the route, in this case, hilly or level? How were the bearings taken, &c.? Nor is it enough that the map-maker satisfy himself by a first process of the confidence he can place on any of their several methods. It may happen that the very results which differ most widely, have been arrived at by means entitled to most credit. Then must he have recourse to collateral arguments derived from other sources, before he come to a conclusion in favour of the one or the other, and is perhaps obliged, after all, to split the difference.

Now it is clear, that this sifting of contradictory evidence is no easy task, and implies extensive information, great patience, and intense application. It will not always do to cut the matter short, by taking the latest observation as probably the most correct. The position of Mexico as laid down by Velasquez and Gamma in 1778, was correct in latitude, and only about fifteen miles too far to the West, while Arrowsmith (the elder), in 1803, places it about thirty-three miles too far North, and forty-five too far West, and the *Connoissance des Temps* for 1804, while it gives the latitude nearly correct, places it in longitude a whole degree too far West. We repeat it, then, little reliance can be placed on any maps, but such as are published by intelligent, painstaking, and conscientious map-makers; their number is very limited, and they are entitled to the gratitude of all who have a just notion of the great importance of correct maps. But a map may be correct, and still not be a good map in every sense of the word, as we shall presently explain.

We have hitherto spoken of the construction of maps from regular surveys from the assemblage and reduction of other maps, and from various sources, still including the use of already executed maps. We have now to say a word on mapping from the mere information of travellers.

MAPPING FROM THE INFORMATION OF TRAVELLERS.—The delineation of countries that have not been surveyed in any way, depends entirely on the relations, the notes, the information received, and the sketches made by travellers. From these sources of knowledge the first details of a country are laid down, and from them the map becomes filled up, and corrected as fresh information is acquired. A few years since, the map of Australia presented one great blank; but the Sturts, the Eyres, the Leichardts, the Mitchells, the Strzeleckis, and other adventurous, indefatigable, and well-qualified travellers have, by their most hazardous and difficult explorations, enabled our map-makers gradually to lay down some important features of that vast island, and consequently increase our knowledge of that singular and even yet little known region. We could also point to Sir R. Schomburgk's travels in Guayana, and Dr. Beke's in Abyssinia, and indeed many others, as examples of the enrichment and correction of our maps by the mere researches of travellers in the absence of regular surveys.

The value of the information supplied by explorers is not always the same; some possess greater acquirements than others, and some have better or more extensive opportunities than others of applying their ability. It can of course be the lot but of very few to unite the varied knowledge of a Humboldt, and bring home as the result of their travels, new facts gleaned from every department of nature, and throw new light upon the questions relating to the several races of mankind, their language, arts, customs, and institutions. Almost every traveller is remarkable for some speciality, and, according to the bent of his inclination, directs his principal attention to this or that particular object; but we have here to deal chiefly, if not exclusively, with his ability as a topographer.

If the traveller be possessed of good instruments for observing the latitudes and longitudes of the several remarkable points of his exploration, and knows how to use them properly, this gives very great value to his indications; for, if his observations can be relied upon, they not only serve to check the data afforded by his bearings and itinerary distances (if he has noted these), but enable us to lay down the points with precision without the aid of any bearings and distances, and of assigning to them their proper places on a conic or any other projection, without those reductions that are indispensable when the distance of points otherwise ascertained is such, that the spherical surface of the earth must be taken into account.

If the traveller be not supplied with the requisite instruments for the astronomical determination of his latitudes and longitudes, or is unacquainted with the use of such instruments, his points must be laid down by bearings and distances. This is a very common mode in rapid exploration, and the result will be the less incorrect, as the cross bearings have been more multiplied and taken with the greater care, and according as the itinerary measurements, whatever these be, are properly reduced with regard to the nature of the ground traversed. A long route thus laid down can hardly be esteemed tolerably correct, unless it terminate at some spot whose position is pretty well known; in this case, its more glaring errors may be compensated. In like manner, if the traveller return to his starting point by another route, the one will serve to correct the other. If, subsequently, another traveller start from some very different direction from the first, and come to any point laid down by him, this new route furnishes an additional means of corroboration or correction, and thus by degrees the map is improved, and tolerable accuracy is at length obtained.

As the traveller proceeds, he does not confine himself strictly to his direct route; he often leaves it to explore to his right and left. He notes the remarkable hills and other objects he sees around him, judges more or less correctly of their distances, and sets down their bearings. He notes the rivers he passes, their direction, their depth, and breadth, and the strength of their currents, marking carefully the day and hour of all his observations. He gleans, moreover, all the information he can from the natives, carefully stating his reasons for believing or discrediting their assertions. Sometimes the traveller maps his route himself, and this greatly assists the professional map-maker's labour. But it too often happens, not only that notes are all the traveller brings home, but that, either through inadvertence on his part, the notes are incorrect, or he may have neglected some important feature, such as a river, or may have stated the direction of it to be the very reverse of what it is, or he may have set down as a fact what he heard from natives, who may, through ignorance or design, have made a false statement. One part of the traveller's notes may be directly contradicted by another; indeed, the sources of error are numerous, and yet it is from such materials that the map-maker is often called upon to protract a traveller's route through an unknown region, and lay down topographical features where there was only a blank before. Great discrimination is therefore required of him, and it is only the rare few who are able and willing to bestow upon their maps that great amount of labour, which, in so many cases is indispensable, and which, after all, only assures an approximation to truth.

Having thus far initiated the reader into the art of mapping, which, as we have before stated, cannot here be treated of *in extenso*, we shall explain what we meant by saying that a map might be correct, and yet not be a good map.

A Correct Map not always a good one.—A great error prevails almost universally in respect to maps—namely, the desire of making them answer all sorts of purposes at once. Most persons expect to find on a map every place, no matter how insignificant it may be; and if their own hamlet or the village where they reside be not set down, are inclined to look upon the map as incomplete. Then, again, they would have all the political divisions and subdivisions, and as many of the physical features as possible, as also historical and statistical indications, &c. Now, there cannot be a more ill-conceived exigence. We have already stated, that a geographical map should contain nothing beyond the capitals, principal towns, ports, harbours, capes, and other prominent features; the general chains of mountains, and principal rivers, and high-roads, and the limits of empires and states. Anything beyond this tends only to confusion. We could mention a striking example in the case of a modern chorographic map, which we have every reason to believe very accurate; we know it to be beautifully executed; but the publisher, from a desire to meet the ridiculous wishes of his numerous patrons, has inserted every hillock in the land, every petty glen and fillet of water, the projected railroads, as well as those executed, the celebrated battle fields, the lighthouses along the coast, the merest villages, and even gentlemen's seats, &c.; and all this on a map of no greater scale than twelve miles to an inch, producing altogether a mass of grey confusion, a crowd of names, many of them insignificant, and which can hardly be read without a glass. This, therefore, though a correct, is not a good map.

SCALE OF MAPS.—The scales of maps must naturally vary with the particular nature of the maps, and should be determined by that alone. Such is the case with all maps constructed in France under authority. But, in our own country, where there exists an exaggerated aversion to centralization, no matter for what purpose, and where the government are too glad of such an excuse for leaving undone many things which they alone could effectually accomplish, everything appertaining to maps is left entirely to the discretion of map-makers, publishers, and vendors, who, in perfect ignorance for the most part of the importance of the scales of maps, do not give the matter so much as a thought; with them the scale is nothing, the size everything, and this is regulated with a view to mere convenience, by the dimensions of the paper they think proper to employ in each individual case, whether for single maps or atlases. So almost invariably is this the case, that when the writer once made inquiry of several map-makers, respecting the scales generally employed by them, of which he requested to be favoured with a list, the answer received from all was to the effect, that to give a list of the several scales they had employed, would be to give a list of all the maps they had published, as they did not believe they had ever issued two on the same scale, though they had made several of the same size.

This is the fault of the publishers much more than of the map-makers; the former employ one of the latter to prepare a map or an atlas. I want it, say they, to be on a sheet of so many inches by so many, or we want a quarto atlas, an imperial quarto, an oblong quarto, a large folio, a small folio, an imperial octavo, &c. The map-maker, thus restricted to size, has to consider how much margin he will leave, and this, with the given dimensions of the paper, determine the size of the engraving; within this size the country must be crammed, whether it contain fifty or only ten degrees of latitude or longitude, and accordingly, in no case is there any relation between the length of the degrees and any definite scale. Thus, for example, an octavo atlas is ordered; the size of the map within its border is 9¼ inches by 7⅓ (the maps being folded in the middle). Now, a map of England and Wales, reduced to these dimensions, will be on a scale of 44·8 miles to the inch. Europe, in the atlas, must be brought within the same dimensions, and here the scale will be 347 miles to an inch, and so of all the other countries and regions included in the atlas, no two of which will be on the same scale, and not in a single case, perhaps, reducible to even an arbitrary scale of inches, without fractions, much less bearing any regular proportion to nature.

The inconvenience of different scales, even, when they are limited and defined, is almost unavoidable in the case of an atlas; but the number of scales may be greatly reduced, as in the better system lately adopted by Mr. Sharpe, of whose atlas we shall say more presently.

The larger the scale of a map, the greater the number and variety of the details it may admit. But it does not follow that because the scale of a map be large, the map must necessarily contain much detail; some very large maps contain much less than some very small ones.

Class maps, or those intended for the instruction of classes in schools, for lectures, &c., are executed on very large scales, in order that such features and names as are traced upon them may be sufficiently distinct to be seen at a distance, and with the same intention they scarcely contain any but the more remarkable features of the region, and no names but those of the most important places and objects.

Library Maps, that is, such of them as are intended to be suspended upon rollers, or otherwise, are usually on a large scale, and, generally speaking, are semi-topographical maps. Their use being for general purposes, they are more full in respect to places than geographical maps, but as they represent large regions they cannot exhibit topographical details.

County Maps are topographical, and accordingly their scale must be large. Such maps are chiefly employed for suspending in town halls and in the board-rooms of the local magistracy, &c.

Road Maps, like library maps, are, or should be, semi-topographical, but their scale is usually determined by the extent of country to be drawn on a portable size for the use of travellers; for portability being a desideratum, it is evident that a road map of all Europe must hardly take up more room in a traveller's baggage, or be less convenient for constant reference, than a road map of our island.

The scales of maps then must vary with their nature and objects; but, unless in a few exceptional cases, the scales best adapted for the different kinds of maps should be regulated upon a principle, and not be left to the arbitrary determinations of any compiler of maps.

One of the great advantages of maps is their pictorial nature, the eye readily receives, and the memory easily retains particular forms, and thus a person who only occasionally consults maps, can immediately recognise a country by the general form of its outline, without the assistance of any name, while a person still more conversant with maps, knows at once where to place his finger on any remarkable town, by remembering its distance from, and position in reference to, some particular portion of the general outline, &c. But these advantages are greatly lessened by the indiscriminate use of all sorts of scales. Every one must have experienced, whenever, in the course of his researches, he has to consult different maps of the same country, the puzzling effect of different scales, and the loss of time in finding out the spot he is looking for, and to which his eye would immediately have guided him, if the scales had been the same, or even some aliquot part of each other. Thus, if after looking for Valladolid on a map of one scale, we go to another map on a very different scale, the probability is, that we shall be some little time in finding it. We may very well know that this city is on the Esgueva, near to its confluence with the Pisuerga, but it will be as difficult to find these tributaries of the Douro as the town itself. Whereas, if the second map referred to were on the same scale with the first, we should put our finger on Valladolid at once. Or, if the second map bore some definite proportion to the first, we should be greatly assisted in our search by knowing what that proportion was. Again, it is very desirable to have a correct idea of the relative size of different countries, and nothing tends more to falsify our conceptions on this subject than the multiplicity of arbitrary scales in use among us.

The Dépôt de la Guerre, in France, have determined that general maps, i. e. those of the four quarters of the world, shall be on a scale of one-two-millionth, or that two millions of metres on the ground shall be represented by one metre on the map, and all other maps on scales determined by successive decimal reductions, or aliquot parts of this. Thus, a degree of latitude of the general map being taken as unity, a degree of any other general map is ·5, ·2, or ·1 of such unity; by which means a regular proportion is maintained throughout the whole series.

If we were to adopt a system similar to that of the French, the radius of the earth would be represented by ten feet six inches, a duodecimal division of which might afford a series of convenient scales for all our maps.

We have stated that, in Mr. Sharpe's Atlas, the number of scales has been greatly reduced, and we gladly hail this as a step in the right direction. The maps of this Atlas are called by the author, *Corresponding Maps*

There are in all fifty-four, constructed upon only four different scales, and according to these scales, the maps are designated by the names of Continental, Intermediate, Divisional, and Enlarged. Of the first kind there are ten; of the second, seven; of the third, twenty-seven; and of the fourth, six; besides which, there is one, that of Switzerland, whose scale is much larger than the rest—two hemispheres and a Mercator map of the world. The linear scale of the Intermediate maps is twice that of the Continental; that of the Divisional, five times that of the Continental; that of the Enlarged, fifteen times that of the Continental, or three times that of the Divisional. The arrangement of this Atlas results in a somewhat different distribution of countries and regions from what is customary, and which, if it has its advantages in some cases, is, perhaps, inconvenient in others. Of the general accuracy of the Atlas we are not prepared to speak, nor would this be the place, under any circumstances, to enter into its details. We observe that the latest discoveries are inserted, and therefore presume that the compilation has been carefully made. We merely notice this Atlas on account of its peculiar features, of which there are two others, besides the small number of scales. Thus, instead of two hemispheres, as usual, we have here four equal sections of the earth's surface; an arrangement not new, though seldom adopted, and which has both its advantages and its defects; the former consisting in greater accuracy as to the form of the several regions of the earth than is possible according to the usual projection, while its defect is the interruption of continuity of the great eastern continent. In the present case, however, this is not, perhaps, of much consequence, the separation being at the fifty-fifth meridian, close upon the confines of Europe and Asia, northward of the Caspian. It is true Persia is cut in two, and a slice of Arabia scinded. The next particular feature of the Atlas is in the adjustment of the scale of English miles to every separate map.

When the earth is considered as a perfect sphere, all the great circles are of the same extent, and accordingly one degree of a meridian is of equal length with a degree of the equator. But the case is otherwise when the true figure of the earth, which is somewhat flattened at the poles, is taken into consideration; for then the meridians are no longer arcs of circles but of ellipses; the arcs, having less curvature as they approach the poles, are arcs of larger circles, and consequently a degree of latitude near either pole is larger than a degree of the equatorial arc, so that if a degree of the latter contain 69·15 British miles, the degrees of the elliptical meridian will differ from this, and be so much the longer as they are nearer the poles. With a view, therefore, to greater accuracy of admeasurement than is customary, Mr. Sharpe has given upon each map the exact number of British miles contained in a degree of its middle latitude. This effort at increased accuracy is praiseworthy, as denoting what we so much wish to see, a desire on the part of map-makers to make their maps as perfect as possible. But, at the same time, when we consider that the very element of the calculation for the number of British miles in each degree of latitude—viz. the amount of depression at the poles, is still matter of dispute, being variously given, as $\frac{1}{304}$, $\frac{1}{321}$, $\frac{1}{335}$, &c., and that, in any case, the fractional difference for a degree amounts only to a few hundredths of a mile, and lastly, that measurements on a map can never be exact,—we do not see that any very material advantage is gained by the system here adopted. Nevertheless, we repeat our conviction that the reduction in the number of scales is an important point effected, and in so far is an example worthy of imitation.

In cases such as that of the Atlas just mentioned, we think it would be a great improvement if the smaller scaled maps were made to serve as indexes to those on the larger scales, by drawing faint lines on the former to show the boundaries of the latter, with corner numbers of reference.

Whatever be the scale of a map, it is much to be desired, for more reasons than one, that such scale be invariably stated. In the first place, it saves the time and trouble of finding out the scale by measurements; secondly, when we know the scale, we can carry it pretty correctly in the eye, so as at a glance to have a tolerable idea of the distances of places from each other; thirdly, it enables us at once to add the scale to the other details in making a descriptive catalogue of maps, and such a catalogue, without the scales being given, is imperfect in one of its most important items.

Be it, moreover, observed that, though most maps have scales affixed to them, they seldom announce any definite proportion; that is, they say, for instance, geographical miles, British miles, &c., of each of which the scale contains a certain arbitrary number, and the smaller divisions are sometimes *units*, sometimes *fives*, or *tens*, or *fifteens*, *&c.*, and if an inch measure be taken in the compasses and applied to the scale, it falls in with none of its subdivisions. In order to supply this deficiency of our maps, the writer has constructed a CHARTOMETROMETER, which, by merely applying it to the central meridian of any map, indicates (with sufficient accuracy for all practical purposes) the scale of the map in number of geographical and of British miles to an inch.

With respect to these British or rather English miles, it may be well to remark, that different map-makers state them differently. Thus, in one Atlas we find on some of the maps 69 English miles to a degree; on others, 69·1, and 69·12. Another Atlas has simply '*scale of British miles*,' without stating how many of them go to the degree. Another, again, has everywhere 69 British miles to the degree; while a fourth has 69·2; a fifth, 69·5; and Sharpe's Atlas, as we have just seen, states the number of British miles to a degree differently on the different maps. Geographical treatises also give the proportions variously. In the midst of this confusion it is not easy to say who is right; the probability is, that not one is strictly correct; for, admitting that our standard measure of length be well determined, the measurements of various arcs of meridians are not so perfectly correspondent as to comprise any exact or invariable number of English miles. The differences, however, are too trifling in amount to be of any practical importance in such measurements as are made upon maps; for even if the amount of depression at the poles were exactly ascertained (which it is not, being variously stated, as we have shown, at $\frac{1}{304}$, $\frac{1}{321}$, $\frac{1}{335}$, &c.), and if the number of British miles to a degree of latitude in different parts of the elliptical meridian were most accurately determined, still straight-line measurements on a map can never be exact by reason of the distorting effects of projection. A more or less close approximation to truth is all that can be obtained, and, indeed, is all that need be sought; and while the scales of British miles vary in two different maps, as, for instance, 69 miles to a degree on map A, and 69·5 on map B, the probability is that in some one direction, or in some particular part of map A, the scale of map B is nearer the truth than that indicated on map A itself, and *vice versa*. It must be borne in mind that we are here alluding only to the small fractional differences in the several statements of the number of British miles to a degree, and that when we assert that these differences are of little practical importance, we are by no means to be understood as saying that the scale of maps is a subject of indifference; on the contrary, we have endeavoured to show that it is a subject of great importance in many respects.

GRADUATION OF MAPS.—The graduation of maps is little less arbitrary than their scales; in one point, however, uniformity prevails, it being the practice to divide the meridians and parallels in the same manner. These divisions themselves vary:—thus, the parallels and meridians are drawn sometimes at every degree, at other times at every second, every fifth, or every tenth degree. This is a matter which, of course, depends much upon the scales of the maps. When the scale is small, the parallels and meridians may conveniently be drawn at every tenth degree, on a medium scale at every fifth degree, and on larger scales at every single or every second degree, and this seems to be the general practice; but that it is arbitrary is evident from the fact of maps by different compilers being differently graduated, though on the same, or nearly the same scale. When the division is by *tenth* degrees, then each of these grand divisions, on the borders of the map, may be subdivided into two portions of five degrees each, and each of these again into five parts or single degrees. When the division is by *fives*, each may be subdivided into five single degrees, and these again into halves, or 30 minutes or geographical miles. When the parallels and meridians are drawn at every *second* degree, then, on the borders of the map these may be divided into two portions, representing each one degree, and these again subdivided into three parts of 20 minutes each, or into six parts of ten minutes each. When the division is into *single* degrees, these may be subdivided into six for 10 minutes each, or into twelve for 5 minutes each.

The object of graduation is the finding of the longitude and latitude of places on the map; but unless in cases where the parallels and meridians are both straight lines, (as in a Mercator projection,) it answers but very inefficiently the purpose intended. When the parallels are straight lines, as in most maps of Africa and South America, the latitude is easily found by placing the edge of a ruler (sufficiently long to reach from the place to the nearest border of the map) against the place and everywhere equidistant from the nearest parallel, when the graduation on the border, at the point intersected by the ruler, shows the latitude.

In the Conical Projection, even when the meridians are straight lines, the latitude cannot be taken from the border of the map, for as this intersects the parallels under very different angles from what the meridians do, the space comprised between any two parallels on the map is much greater at the border than elsewhere; indeed, the exact latitude can hardly be found but by drawing an arc concentric with the parallels on the map, and passing through the place; but in order to do this, the common centre of the parallels must be found, which it is always difficult and often impossible to do.

The longitude may be approximately found on the conic projection, when the meridians are straight, by placing a ruler of sufficient length close upon the place, and in such wise that it may intersect the same degree of longitude marked on the top and bottom borders of the map. In those maps where both the meridians and parallels are curved, the border graduation of the map only supplies the means of a very rough measurement or guess at the longitude and latitude of any place. It would be a decided advantage if the central meridian of all maps were graduated for the latitude, and this might very easily be effected without the slightest inconvenience or disfigurement of the map; and when the other meridians are curved, the graduation for longitude should be marked on some convenient part of every parallel, between any two contiguous meridians. By this means, and with the aid of a pair of compasses, the latitude and longitude of any place might be found pretty exactly.

CONVERSION OF LONGITUDES.—In the graduation of maps, the longitude unfortunately is not always reckoned from the same meridian. Thus, Ptolemy fixed his first meridian at the Fortunate Islands (the Canaries), as being the most westerly country known in his time, though the precise point is still doubtful.

Louis XIII. ordered that the first meridian should be drawn through the Island of Ferro, the westernmost of the Canaries. • Delisle had made out the longitude of Paris twenty degrees to the eastward of this; but subsequent and better information gave 20° 5′ 50″ for the longitudinal difference of the two places. The first meridian was accordingly shifted 5′ 50″ to the East, so that, at the present day, the meridian of Ferro is quite conjectural, and passes by no remarkable place.

By the Dutch the first meridian was made to pass over the Peak of Teneriffe.

Gerard Mercator chose for the first meridian that which passes over the island Del Corvo, one of the Azores, because, in his time, the needle there showed no variation.

At the present day, however, almost every country considers as first meridian that which passes over its own capital or observatory. Thus, the French reckon from Paris, the English from Greenwich, the Spaniards from Cadiz or Toledo; the Russians have hitherto, like ourselves, reckoned from Greenwich, though occasionally from Ferro; but it is probable, now that they possess a magnificent observatory at Pulkova, near St. Petersburg, they will reckon their longitudes from that place. The Anglo-Americans reckon from Washington, the Venezuelans from Caraccas, and, as M. Jomard observes, the Australians may perhaps ere long have their own first meridian.

The following table will show the longitudes of the principal first meridians with reference to Greenwich:—

	WEST.					EAST.		
Toledo . .	3°	59′	7″	Greenwich	Paris . . .	2°	20′	23″
Cadiz . . .	6°	17′	22″		Pulkova . .	30°	29′	38″
Ferro . .	18°	9′	37″					
Del Corvo .	31°	3′	00″					
Caraccas . .	66°	44′	37″					
Washington	77°	2′	1″					

When to this diversity be added, that some geographers reckon the longitude eastward all the way round the equator from 0 to 360, while others count both eastward and westward, 180 degrees each way, and that some deduce their longitude from some particular meridian not considered as the first by any people, it will be easily conceived what confusion exists in this matter. Indeed, the perplexity is often great when we would know the longitude of any place, as reckoned from different meridians, or in different ways from the same meridian. Some map-makers (and this is a great oversight) do not even state upon their maps from what first meridian the longitude is reckoned. When the first meridian and the mode of counting are known, a calculation is necessary whenever we would refer the longitude given, to what it would be if reckoned in a different way, or from some other first meridian.

The longitude reckoned all the way round is called the *Geographical Longitude;* that which is reckoned only half-way round, East and West, is called the *Nautical Longitude*, and accordingly, as we have to deal with the one or the other, the mode of reduction is different.

In the first case, (that is, reckoning the longitude all the way round,) when we would find, from the longitude as given from any particular first meridian, what it would be reckoned from any other first meridian, the rule is—

Take the difference of the two first meridians, and if the one from which we are desirous to count be to the westward of that given, *add* the difference to the given longitude; but if it be to the eastward, *subtract* it.

1st Example.—The given longitude of Calcutta is 271° 32′ East of Paris. Query—what is its longitude from Greenwich?

Greenwich is 2° 20′ 23″ *West* of Paris, consequently 271° 32′ + 2° 20′ 23″ = 273° 52′ 23″.

2nd Example.—Moscow, given longitude from Ferro, 55° 14′ 45″. Query—what is its longitude from Paris?

Paris is, 20° 30′ East from Ferro; accordingly 55° 14′ 45″ − 20° 30′ = 34° 44′ 45″.

If, after the addition, the whole be more than 360 degrees, which may often happen, then the rule is—

Subtract 360 degrees from the larger sum, and the remainder will be the longitude sought. Thus—

3rd Example.—Madrid is 353° 57′ 40″, Geographical Longitude, East of Paris. Query—what is its longitude, counted after the same method, from Ferro?

Ferro is 20° 30′ *West* from Paris. Then 353° 57′ 40″ + 20° 30′ = 374° 27′ 40″;

this is more than the whole circle; accordingly 374° 27′ 40″−360° = 14° 27′ 40″, the geographical longitude from Ferro.

Again: if the given longitude be less than the meridianal difference to be subtracted, the rule is—

Add 360 to the longitude, and then subtract the difference.

4th Example.—The Island of Gomera is 32′ from Ferro. Query—what is its longitude from Teneriffe?

32′+360°=360° 32′, and the difference of the meridians being one degree, 360° 32′−1°=359° 32′, which is the geographical longitude of Gomera from the Dutch first meridian of Teneriffe.

In the case of *Nautical Longitude* to be reduced to *Geographical Longitude*, we may observe, that when we reckon from one and the same first meridian, the geographical and the nautical longitudes are the same as far as 180° East. In the case of *West* longitude, the rule is—

Subtract the given West longitude from 360, and the remainder will give the geographical longitude. Thus—

5th Example.—Icy Cape is 161° 30′ *West* of Greenwich. Query—what is its geographical longitude?

360°−161° 30′=198° 30′.

It is self-evident that by the inverse operation, geographical longitudes above 180° may be turned into nautical longitudes by subtracting them from 360. Thus—

6th Example.—The geographical longitude of Icy Cape is 198° 30′. Query—what is its nautical longitude?

360°−198° 30′=161° 30′, West.

But if the case regards two different first meridians, or starting points, then the rule is—

See first whether the meridian to which we would refer the longitude be to the East or to the West of that from which it is given; then *subtract* the difference of the meridians, when they are of the same name, and *add* when they are of contrary denominations. Thus—

7th Example.—Constantinople is 29° *East* of Greenwich. Query—what is its longitude from Paris?

Now Paris is 2° 20′ 23″ *East* from Greenwich; therefore

29°−2° 20′ 23″=26° 39′ 37″.

8th Example.—Cape Horn is 67° 21′ 15″ *West* from Greenwich. Query—what is it from Paris?

67° 21′ 15″+2° 20′ 23″=69° 41′ 38″ West.

It sometimes happens that the place whose longitude is to be reduced lies between the meridian given and the one to which we would refer it; being to the East of the one, and to the West of the other. In this case the rule is—

Subtract the longitude from the difference between the meridian given, and that to which the place is to be referred, and change its denomination. Thus—

9th Example.—Dover is 1° 18′ 30″ *East* from Greenwich. Query—what is its longitude as referred to the meridian of Paris?

The difference of the two meridians of Greenwich and Paris is 2° 20′ 23″, therefore 2° 20′ 23″−1° 18′ 30″=1° 1′ 53″ *West* from Paris.

What happens in reference to places situated between the meridian given, and that to which a place is to be referred, may also happen in respect to their opposite meridians. Thus, when instead of subtracting, we have to add to the given longitude the difference between the meridian from which it is reckoned, and that to which we would refer it, we sometimes find it greater than 180 degrees. In this case the rule is—

Subtract the sum from 360°, and change the denomination. Thus—

10th Example.—Tortoise Island is in 177° 57′ *West* longitude from Greenwich; what is its longitude from Paris?

As in this case, the difference of longitude between Paris and Greenwich is additive, 177° 57′+2° 20′ 23″=180° 17′ 23″, which being more than half the equatorial circle, must be subtracted from 360°. Thus—

360°—180° 17′ 23″=179° 42′ 37″ *East* longitude from Paris.

From the above examples it will readily be seen, how very desirable it is that some *one* first meridian be adopted by all nations; this desideratum has been frequently and loudly insisted upon by the most eminent geographers of Europe, but it is to be feared, alas! that absurd national prejudices will ever stand in the way of so desirable a reform, as it does in that of many other important changes.

Details of Maps.—A very great deal might be said on the details of maps, such as the choice and size of the character used for the names of the several objects; the limitation of the double lines of rivers to the extent of their navigation; the modes of indicating the mountain chains, &c. The colouring of maps; the kind of paper best suited to maps of different kinds; the best methods of mounting, arranging, and cataloguing them, and many other matters; but to go into these details would be to lengthen the present article far beyond the limits to which we must of necessity restrict ourselves. For the same reason, we have been unable to give any history of the progress of map-making, or to say anything of ancient maps, such as the *Catalans*, the *Portulans*, &c. Indeed, as we stated at the commencement of the present chapter, the subject of Chartography, fully treated, would of itself fill a large volume, and require to be illustrated by many and expensive plates.

We cannot, however, close the present article without protesting against the general want of attention to the orthography of maps. Surely something like greater uniformity in our manner of writing foreign names might be effected. The Royal Geographical Society have long since established a rule for the orthography of Oriental names, which is both simple and judicious, and if adhered to in maps, in books of eastern travels, and in geographical works, would go a great way to diminish the confusion of which every one so justly complains. The system to which we allude is as follows:—

Geographical Orthography.—The orthography, as far as possible, is reduced to a fixed standard, each letter having invariably its corresponding equivalent. The consonants are to be sounded as in English, the vowels as in Italian. The accents mark long vowels, and the apostrophe the letter 'aïn; *gh* and *kh* are strong gutturals; the former often like the Northumbrian *r*, the latter like the Scotch and Welsh *ch*: *a* as in far; *e* as in there; *i* in ravine; *o* in cold; *u* in rude, or *oo* in fool; *ei* as *ey* in they; *au* as *ow* in fowl; *ai* as *i* in thine; *ch* as in child.

What has thus been done for eastern names, might in like manner be effected for those of the Slavonic nations, Russia, &c. But to expect improvements of this kind, would be to look for an amount of zeal and industry on the part of our map-makers for the real interests of the science, which we are not likely to find.

We must now conclude this brief memoir on maps, which, imperfect as it is, will, we hope, prove acceptable to our readers.

PHYSICAL GEOGRAPHY.

By David [illegible]

PART I.

OF THE EARTH'S SURFACE.

CHAPTER I.

INTRODUCTION.

§ 1. General outline of the subject.—2. Divisions of the subject.—3. Planetary condition of the earth.—4. Elemental conditions of matter.—5. Mechanical conditions of matter, and divisions of science thence resulting.—6. Advantage arising from the study of Physical Geography.

GENERAL Outline of the Subject.—If, in a system of geography it is thought necessary to explain in detail those facts which bear upon the occupation of the earth by man, it is not less important to communicate a general view of the various mutual relations of the inorganic and organic bodies met with on the Earth's crust, however these may sometimes have been neglected by writers whose views were limited to the more technical part of the subject directly before them.

Such general views and discussions it is the object of PHYSICAL GEOGRAPHY to furnish, and to this the science thus designated is properly limited. It regards the human race in its relations with external nature. It has, however, no concern with human history; nor does it directly introduce those important commercial interests which bind together different branches of the great human family. It deals not with artificial boundaries of nations, or with the position and relative importance of those localities where men congregate in multitudes. It makes no reference to the habits of men, or the distinction of races, except when these, in their turn, affect the general grouping of organic beings on the globe.

The scope and objects of this science are, however, sufficiently interesting, and bear in no trifling degree on the most important interests of men.

Physical geography is the history of the earth in its whole material organization;—as a planet, inasmuch as it affects, and is affected by, the other planets of our solar system, and all other bodies in space; as a mass of matter, whose external crust exists in various mechanical conditions acting on and affecting each other; as the seat of organic life, consisting of certain tribes of vegetables and animals adapted to its present state; as subject to certain mechanical and chemical changes which modify the conditions of organic existence; and, lastly, as containing and exhibiting in its solid portion a history of itself in former states, and when inhabited by different organic beings, thus affording memorials of events and changes that have occurred at and near its surface during the lapse of a vast period of time, if not from the very commencement of its existence as a planet.

2 *Divisions of the Subject.*—The fundamental knowledge required to comprehend the science of physical geography consists, then, of many and varied facts concerning—1st, the planetary conditions of the globe; 2nd, the nature, properties, and chemical and mechanical conditions of the portions of matter which make up the Earth's crust; 3rd, the general form and manner of distribution of the solid, fluid, and aeriform parts which are presented for observation at and near the surface; 4th, the nature and distribution of

existing races of vegetables and animals; and 5th, the former grouping of these organic bodies, as determined from their remains existing within the Earth's crust, and discoverable by investigation and inference.

3 *Planetary Condition of the Earth.*—The material universe comprises a vast but unknown multitude of bodies, made evident to our senses by their power of emitting or reflecting light, but connected together also by the universal action of one great law—that of gravitation. All these bodies, although at immense distances apart, act upon each other in very important ways. They are collected into groups, of which the one to which our Earth belongs consists of a central body, the Sun, which is self-luminous, and a number of smaller bodies, the planets, revolving round it, and only reflecting light; but themselves, in many cases, the centres of motion of others, still smaller, called moons or satellites. The group altogether is not remarkable amongst the heavenly bodies, and our Earth offers no peculiarities of importance either with regard to magnitude, position, or other essential qualities.

The Sun, the central body of this system, is of great magnitude compared with any of the bodies revolving round it, and it seems to be the only one of the whole number which is capable of emitting any considerable amount of light and heat. Although many times larger than all the members of our system together, it is not so dense as most of them, and in consequence of the external surface being luminous in a high degree, it has not been found possible hitherto to do more than measure its dimensions, distance, and relative density. Of the other bodies, most of the planets revolving round the Sun in various periods appear to possess many analogies with each other and with our Earth; while the satellites or moons, of which the Earth has one, revolve round the planets, and appear to differ from them in some respects. Comets are wandering bodies, apparently self-luminous. They revolve in elliptic and irregular orbits round the Sun, and are so extremely anomalous, that little has hitherto been determined concerning them except that they are probably gaseous. The stars appear to be self-luminous, but their distances are far too great for us to be able to determine anything with regard to their mechanical and chemical condition, leaving us only to assume their vast magnitude and the extent of the systems to which they belong.

Thus, then, the Earth, unimportant as it is as an individual member of the countless hosts of heaven, becomes to us, its inhabitants, not only important as our dwelling-place, but as the only object in space concerning which we have the means of minute investigation; for however the distant views of other bodies may communicate true general notions of their real state, we can observe and investigate only those things presented to us here and capable of direct and experimental handling. Thus it is that our ideas of the conditions of matter are limited to those commonly presented to our senses, and our notions of forms of life are similarly confined, nor does it seem altogether possible for us to imagine other conditions or other forms without running into extravagant and even ridiculous exaggeration. It is not, however, really essential to the existence of a planet, and it may not be needful for organic existence, that matter should be invariably presented in the ways in which we are accustomed to see it. The conditions that obtain on our Earth may not be universally met with; the ultimate elements of which another planet is composed may be different from those here found; the proportions in which those elements are combined in the most abundant and characteristic materials are still more likely to be different; the proportion of light and heat, the extent and nature of chemical and electrical action, may be capable of infinite variation; and when the limits of one planet are passed, the forms so familiar to us as to seem essential to matter may entirely alter, and new and unimagined contrivances appear, producing results not less perfectly and beautifully adapted to existing circumstances.

4 *Elemental Conditions of Matter.*—In order to understand how this may be, it is necessary to be familiar with the true actual conditions of matter and life on our globe; and thus arise, at the outset, various considerations

concerning the materials of which the earth is built up, the ordinary and rare combinations of the material elements, their mutual action, the causes of internal change and modification that can be traced amongst them, and the mechanical condition of the various kinds of material, and their mechanical action on each other.

So soon, then, as we commence investigations of this kind, we find ourselves, in fact, launched on an inquiry which includes within its wide embrace two special sciences of immense extent and vast importance. CHEMISTRY, in its highest sense, and MINERALOGY are required at the starting point, and must form the basis of all accurate knowledge of the Earth. These teach us that the materials of the Earth's crust are combinations of various substances, and that the cause, as far as we can discover, of their peculiar condition is connected with the presence of an imponderable agent, which, whether called by the name of light, or heat, or electricity, or chemical force, is not less connected with, and derived from, other bodies of the universe, than are the known effects of that great law of gravitation, which knits together into one group all material bodies.

Thus, the result of the very first inquiry is to complicate the problem, and refer us back to those very bodies concerning which we know so little. But it is altogether in harmony with everything yet discovered in nature that there should be these mutual relations, and no real isolation. The same kind of mutual influence is met with everywhere, and appears to form a chain of evidence evincing a marvellous unity of design in the whole creation.

5 *Mechanical Conditions of Matter, and Divisions of Science thence resulting.*—When, however, by a reference to all that is known of the laws of chemical force, and the nature of chemical combinations, and when, by careful examination of those substances which are most abundant and most important in nature, we have obtained a knowledge of the materials which form the Earth's crust, we are next introduced to a phenomenon of the mechanical condition of these substances, which is of the most singular interest, and is productive of the most essential characteristics of organic existence, and also of a constant modification of the Earth's crust. In consequence of the nature of the combinations, and the actual temperature of the Earth's surface, the three mechanical conditions of solid, fluid, and aeriform are assumed by different kinds of matter, the result being that we have a solid crust of irregular form, the irregularities being partly occupied with water, and the whole invested with a transparent veil of air. The mutual action of these is the source of a great multitude of phenomena to be described under various distinct heads. The science of METEOROLOGY, or the phenomena of the atmosphere; HYDROLOGY, or the phenomena of water, including not only the sea and rivers, but all other portions of the aqueous covering of the globe; together with a description of the modifications of the existing surface by various causes, thus require minute attention amongst the facts of physical geography. The actual distribution of land and water on the globe, the configuration of continents, islands, &c., the description of the mountain ranges, and the river systems, the great plains of the Earth, the valleys, and other striking phenomena of form and configuration, these complete another of the main branches of the subject.

The internal structure of the Earth, and the reaction caused by the conditions of matter beneath the surface—involving much of the past history, as well as the present state of our globe—is another department of the subject; while the generalizations obtained by an accurate and detailed study of every organic body that comes under man's observation, whether actually now endowed with life, or having existed only in distant ages, and long since extinct—all these together make up the physical history of the earth, or, in other words, the science of physical geography.

6 *Advantage arising from the Study of Physical Geography.*—The study of such phenomena as those here alluded to may be regarded not merely as promoting the interests of man in reference to his material wants, but also

as greatly affecting his general intellectual advance. This has been well remarked by Alexander Von Humboldt, whose knowledge of external nature is, perhaps, greater than has been acquired by any man of our own or former ages, and who, in the introduction to his *Cosmos*, has admirably touched upon the advantage of such knowledge and the objections that have been raised to it. I shall not hesitate to avail myself of the expressions of so admirable a writer to illustrate this part of my subject. He remarks that, 'it is the intuitive and intimate persuasion of the existence of these relations which at once enlarges and elevates our views and enhances our enjoyment. Such extended views are the growth of observation, of meditation, and of the spirit of the age, which is ever reflected in the operations of the human mind, whatever may be their direction.

'Special accounts of districts, and minute statements concerning those portions of external nature presented for our investigation in a single country are, no doubt, the most available materials for a general physical geography; but the most careful successive accumulation of such descriptions would be as far from affording a true picture of the general conformation of the irregular surface of our planet and the general conditions of matter at, above, or beneath its surface, as a list and account of all the species of plants or animals found in different districts would be from communicating knowledge concerning the general geography of plants or animals.'* This latter subject, the geography of plants and animals, involves the grouping of organic beings—the extracting from minute individual accounts that which is common to them all in regard to their climatic distribution—the investigating the numerical laws, or the proportion of certain forms, or particular families, to the whole number of species—the assigning the geographical position of the district, where in the plains each form reaches its maximum number of species and its highest organic development. So, also, the final aim of physical geography is to recognise unity in a vast variety of phenomena, and by the exercise of thought, and the combination of observations, to discern that which is constant through apparent change.

If, however, we would comprehend existing nature, we must not separate the consideration of the present state of things from that of the successive phases through which they have previously passed, and thus we have the word *history* fitly introduced with reference to nature, and the phrases 'natural history' or 'history of nature' strictly adapted to descriptions such as we contemplate. The organic world—that portion of nature endowed with the mysterious principle of life—is, as every one is aware, constantly exposed to change, so far as the individual is concerned; and a careful study of the relations that exist amongst organized bodies shows that this principle of change extends also to those natural groups of similar individuals, which we denominate species. But it is not only in the organic world that matter is constantly undergoing change, and becoming resolved into its elements, in order that these elements may enter into new combinations—such is the case, also, with the inorganic materials, which are never permanently in repose, and which have undergone many and important modifications, evidenced by the condition of those strata of sedimentary rocks which compose a large part of its crust, and which also contain numerous early forms of organic life now totally lost, but originally associated in groups which have successively replaced each other.

Vast, therefore, and complicated in a high degree are the phenomena, and grand are the generalizations with which we have to deal in considering fully the subject before us. It is founded on absolute facts, and on the observation of what actually takes place and exists, but it involves the expression of many phenomena co-existing in space, and an account of the simultaneous action of numerous and conflicting natural forces. A view of the effects of time, and

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* See Humboldt's *Cosmos*, Col. Sabine's translation, vol. i. p. 47.

the analogy of the effects of time and space with regard to the distribution of organic beings, together with a general history of all terrestrial phenomena in their mutual relations, render it at once a uniform and comprehensive science.

Little has hitherto been attempted on the plan proposed in the present work, to present in one view the principles of geographical science, and afford means of studying this science on its true basis. Many important facts of physical geography have, however, been accumulated by various authors, and have lately been arranged, both in Germany and England; and while in the present outline the plan and method are altogether distinct, including also a wider range than has hitherto been thought necessary, the author has been indebted to his predecessors, and to the works of many naturalists and travellers, for the substance of what is given. The *Cosmos*, and other works of Alexander Von Humboldt, Johnston's *Physical Atlas*, Hoffman's *Physikalische Geographie*, and in some cases Mrs. Somerville's *Physical Geography*, as well as several admirable articles in the *Penny Cyclopædia*, will be found freely quoted, though generally not without acknowledgment.

CHAPTER II.

FORMS AND MODIFICATIONS OF INORGANIC MATTER.

§ 7. Limits of our knowledge with regard to the earth's structure, and importance of heat as an agent of change.— 8. Forms of matter.— 9. Forces affecting matter, and effect of change of temperature.—10. Sources and causes of heat.—11. Chemical action.—12. Polarity.—13. Material substances usually in combination at the earth's surface.— 14. Elementary substances.— 15. Oxygen gas, and its important combinations.— 16. Combustion.— 17. Nitrogen, hydrogen, and chlorine, with their combinations.— 18. Non-metallic solid elements.—19. Metallic elements the bases of earths.—20. Metals.—21. Mutual action of various forms of matter.— 22. Terrestrial magnetism.

LIMITS of our knowledge with regard to the Earth's Structure, and importance of Heat as an Agent of Change.—The knowledge that has been acquired with regard to the Earth is very limited in some important respects, but involves much interesting detail in others: it teaches much, but leaves also very much untaught; part of which is at present beyond our comprehension, and part we can never hope to learn.

We know, for example, the form of our Earth and the density of the mass, we can compare this density with that of matter at the surface, and we can also determine the absolute weight of the whole globe. All these conditions exhibit direct reference to temperature; and we learn by observation, that while the temperature at the Earth's surface varies at different parts, having relation to the solar rays, the temperature at a certain depth below the surface is in all parts of the Earth uniform; while below this stratum of uniform temperature, there is an increase of heat with increasing depth, not altogether regular and uniform, but sufficiently so as to render it highly probable, that at a considerable distance down the heat is sufficiently intense to produce fusion of even the most refractory substances met with at the surface. The increase being about one degree of Fahrenheit's thermometer for every fifty-five English feet of depth at all known depths, this, if continued in the same arithmetic ratio, would produce the melting point of granite at a depth of about twenty miles below the surface.

When, too, we remember that the temperature of the surface is so greatly affected by the position of the Earth with regard to the Sun, as to admit of innumerable climatal peculiarities, especially of those periodical changes we call *Seasons*; when we further consider the effect of light, and the important relations of light and heat with electricity, galvanism, and magnetism, the vast importance of the subject of heat will be understood, and the reason for devoting some space to a consideration of the forms of matter, and their relation with this and other imponderable agents, will be fully recognised.

8 *Forms of Matter.*—In the general views that may be taken of natural substances, certain relations appear which afford the means of arranging them in distinct classes, each distinguished by certain sensible and obvious qualities.

The first class consists of *Solids*, under which form most of the known part of the globe is presented. When in small masses, solid bodies retain whatever mechanical form may be given them:—their parts are separated with difficulty, and cannot be made to unite readily after separation. Some (called non-elastic) yield to pressure, and do not recover their former figure; others (called elastic) regain their form, after losing it by pressure. They differ from each other in degrees of hardness, in colour, transparency, and weight, and when having definite crystalline forms, in the nature of these forms.

The second class consists of *Fluids*, of which there are fewer varieties. These, in small masses, assume the spherical form: their parts possess freedom of motion; they differ in degrees of density and tenacity, in colour and degrees of transparency. They are usually regarded as incompressible. They are contained in or repose on solids, and assume the form of the vessel in which they are placed.

The third class includes *Elastic Fluids* or *Gases*, which may either exist free in the atmosphere, or be confined by solids and fluids. Their parts are highly moveable, they are compressible and expansible. They are all transparent, and very rarely present colour. They differ materially in density.

It has been supposed by some natural philosophers that there exists also a fourth kind of matter, which has been called *Ether*, occupying the spaces between those aggregations of matter which form suns, planets, comets, and satellites. The phenomena of light, heat, and electricity, and their relation to the Sun in our system, have been thought to require the existence of some intervening material substance in order to admit of the action of forces or powers recognised under those names.

9 *Forces affecting Matter, and effect of Change of Temperature.*—All matter is subject to the law of gravitation, by which one portion is attracted to another in proportion to its mass, and inversely as the square of the distance intervening. Matter existing at the Earth's surface exhibits also the action of a force called *cohesion*, which preserves the form of solids, and gives globularity to fluids. This force is, therefore, a prime cause of the permanency of the arrangements to which we owe the surface of the globe.

When any substance in a state which occasions the sensation of heat to our organs, is brought into contact with another body which has no such effect, the result of their mutual action from the difference of these conditions, is that the hot body contracts and becomes cooler, while the cold body expands and becomes warmer.

The effect of heat is, therefore, generally to cause the particles of bodies to separate from one another, and heat is communicated either by actual contact, or by means of rays transmitted from the one body to the other.

As, however, there is nothing to affect the weight of bodies in the communication of heat to them, and they occupy larger space, after being heated, than they did before, they must then become less dense.

In the case of matter in the liquid or aerial form, the communication of heat is found by experiment to take place by currents, or particles actually moving amongst each other. How far currents may be induced in bodies in a solid state is not easy to decide. The effect of circulation thus produced is easily recognised in the atmosphere, since the unequal heating of the Earth by the Sun produces wind; and it is seen also in currents produced in the ocean.

When a substance in a fluid or solid state is exposed to the action of heat, a change of condition takes place, the solid becoming at first fluid, and then assuming the aerial or gaseous state. When, on the other hand, fluid or aerial bodies are made to part with their heat, they assume in most cases a solid form. Thus most of the gases become fluid, water becomes ice, &c.

Generally, when a change of condition takes place in consequence of the addition or abstraction of heat from various bodies, the addition of heat produces expansion, and the subtraction of it contraction; but the amount of change of volume is different for different substances, and material bodies change their states at very different temperatures. Owing to this it is that the matter at the earth's surface assumes the form of solid land, with a watery ocean floating on the surface and filling up inequalities, while the atmosphere floats evenly over the whole. We have here exemplified the three conditions of solid, fluid, and aerial.

Although, however, generally the alteration of volume in different bodies is uniform during similar changes of temperature—that is, although bodies generally contract regularly while heat is being regularly taken from them, and expand regularly during similar increase of temperature, this is by no means invariably the case. There are many exceptions, but one is of vital importance to every organized being on the Earth, and has had much to do with the general constitution of the Earth's crust. Water contracts regularly as it cools down to a certain point; it afterwards expands slowly as the heat is farther reduced, and as it congeals or assumes the solid form, it expands considerably, so that ice, instead of being heavier, is lighter than water, and floats on its surface. Were it not so, the sea in cold latitudes would become gradually frozen into a mass of ice, which the bright and warm sun of summer would have little effect upon. In point of fact, however, water congeals only at the surface, where it is liable to be acted on by the sun and by warm currents of air, which tend to restore it to the fluid state. When the water in a lake, or in the sea, approaches near the freezing point, it begins at once to descend, diminishing in volume and becoming, therefore, heavier, so that no ice can be formed till the whole of the water has been cooled to the point where it possesses greatest density. When the ice is once formed, it increases in thickness very slowly, the solid form of water being a very bad conducter of heat.

10 *Sources and Causes of Heat.*—The cause of heat is by no means clear, and there are many modes of producing it besides exposure to the sun's rays. A piece of Indian rubber extended and suffered to contract rapidly several times, becomes hot; a nail is made red hot by hammering; the axle of a carriage takes fire by rapid motion, when the friction is not diminished by grease; the sudden compression of fluids and gases also produces heat; and, on the other hand, when by the air-pump a receiver is rapidly exhausted of part of its air, the sudden expansion of the remainder produces a considerable diminution of temperature. All these facts prove that one immediate cause of the phenomena of heat is motion.

Since matter may be made to fill a smaller space by cooling, it is evident that the particles of matter must have space between them It is also possible that the particles themselves may be actually smaller than the intervening space in the ordinary condition even of solids, and thus in all cases currents of these particles may be produced during the transmission of heat and the action of other imponderable agents.

11 *Chemical Action.*—The various material substances met with in nature are not only in different mechanical conditions, but are also variously acted upon by each other. If, for example, we take the three substances, oil, water, and soap-lees, it is easy to show that the oil and water will not mix or act upon each other; the oil will separate itself from the water and arrange itself according to its weight, the two fluids not in the least combining. On the other hand, the soap-lees will mix intimately with the water, having none of its properties altered. But if the oil and soap-lees are mingled, they will

unite, forming a soft solid substance, which is, in fact, a species of soap, and differs materially from either of its constituent parts. Many substances in nature have thus what is called *affinity* for each other, combining intimately, and the kind of attraction exhibited when two bodies have this affinity is called *chemical action.*

Different bodies, however, unite with different degrees of force, and one body is capable of separating others from certain combinations, so that mutual decompositions of different compounds take place under favourable circumstances, and new combinations and new compounds are formed. This has been called double affinity, and it involves a kind of preference of one body, or set of bodies, over another. It is thus often described as *elective affinity.*

Now, it is very important to understand the difference in kind, of those two forces which have been called respectively attraction and chemical affinity. Attraction, whether that of gravitation, cohesion, or what has been called adhesion (illustrated by the holding power of glue, mortar, &c.), never in any case effects a change in the properties of bodies. On the other hand, when two substances that have affinity are brought into close approximation, and the affinities come into play, great and decisive changes take place in the two bodies, and a new substance is formed, which may be altogether different in all its essential characteristics from either. This action is best effected when the particles are most free to act on each other, and thus the addition of heat or fluid often facilitates considerably changes of this kind. The order of affinity is a matter also of great importance and interest.

12 *Polarity.*—There is yet another force exerted on bodies, and tending to produce the condition of things observable at the surface of the earth. It is best described by the word *polarity,* and is exemplified by that form of polarity exhibited in a bar magnet, which tends to place itself (when suspended freely) in a certain position with reference to two opposite ideal points in space—the north and south pole—near the extremities of the ideal axis round which the earth revolves. The magnet also attracts to itself at one end, and repels from the other, the extremity of a similar piece of iron also magnetized. Chemical polarity, however, involves much more than ordinary magnetic action, and must in the present state of science be understood to include electricity and galvanism, as well as magnetism, if not light, heat, and chemical affinity. The form known as galvanism is that which exhibits most of the peculiar results of this force, while that called magnetism is not less interesting, as showing in some respects the most familiar, as well as distinctly marked phenomena of polarity, presented in a moderately simple form. Electrical attraction and repulsion are equally striking, and not less simple in illustration.

Electric or galvanic action is generally connected either with the evolution of heat or chemical decomposition, and is excited by heating or rubbing certain solid substances, and by the contact of others of different kind when immersed in certain fluids. Changes of temperature at the Earth's surface, however, elicit magnetic and electric currents, and these again produce results which are among the most interesting that are met with on the globe. The Earth itself may be regarded as a magnet, and terrestrial magnetism may thus be ascribed either to inequalities in the temperature of the globe, or to those galvanic currents which we regard as electricity moving in a circuit. Scarcely any important change can take place in the atmosphere without the disturbance of electric equilibrium.

13 *Material Substances usually in combination at the Earth's Surface.*—The intimate action of these forces, if they are distinct, or the various modes of action of this one most varied force, if indeed there is but one, have produced those combinations which are presented at the Earth's surface, and have formed this variety of condition which is there recognised. Thus it is that some solids are constantly on the verge of change, under ordinary conditions, while others are so permanent as to yield scarcely, if at all, to the

most extreme action of this force that we can bring to bear upon them. While, also, some bodies are occasionally permanent in the fluid form, others can hardly be preserved in that form when very slight changes of temperature occur, and some of the aerial or elastic fluids are so little affected by the abstraction of heat or increase of pressure, as not yet to have yielded to the greatest efforts that have been made, although others are readily altered and made to assume the liquid form. Some decompositions also are easily effected, while others are so only with extreme difficulty; so that the chemist, whose object it is to determine the ultimate constituents of matter, is often at a loss to know whether, after all his labours, he really obtains an elementary body, or has to account for effects produced by assuming the admixture of portions of a body whose properties are not yet even imagined.

Notwithstanding this doubt of the ultimate elements, since it is necessary for the purposes of science to have certain principles and generally acknowledged facts from which to proceed, it has been found convenient to regard all those bodies which no art has yet been able to decompose as elementary. Thus it is usual to speak of a considerable number of elementary substances, many of which, however, may be really compounds, and many are so extremely rare in nature, or present in such small quantities, that in general descriptions they may almost be neglected.

14 *Elementary Substances.*—Of the so called elementary substances, several are abundant and well known, and others are highly important in combination, though of themselves rarely or never seen. They are of two very distinct kinds—those which are metallic, and those non-metallic. The whole number certainly known at present is fifty-nine, of which forty-three are metals, and five gases; but of this number only about thirteen are abundantly present in the rocks that make up the mass of the Earth's crust. The rest are chemical or mineralogical curiosities, or else occur in quantities so small as not greatly to affect the whole mass, however useful and important to man.

The thirteen elementary (?) substances most abundantly distributed are the following:—

Four gases—*oxygen, hydrogen, nitrogen,* and *chlorine;*
Three non-metallic solid elements—*silicon, carbon,* and *sulphur;*
Five metals, important as alkaline bases—*calcium* (basis of lime), *sodium* (basis of soda), *potassium* (basis of potash), *magnesium* (basis of magnesia), *aluminum* (basis of alumina, the ingredient of clay);
One true metal—*iron.*

15 *Oxygen Gas and its important Combinations.*—*Oxygen gas* is beyond all comparison the most abundant material present at the Earth's surface, for although not met with in a free state, it is found mixed with nitrogen forming the atmosphere, with hydrogen forming water, and with silicon, calcium, sodium, potassium, magnesium, aluminum, constituting various substances known as silica or flint, lime, soda, potash, magnesia, and alumina. It also forms, with iron and other metals, a vast number of the most abundant of the ores and minerals. On the whole, as much as one-half by weight of the materials of the Earth's crust consists of this gas. Oxygen gas is colourless, and a little heavier than atmospheric air. It may be made to unite with all the other elements except one (fluorine), and in many cases its combination, atom for atom, with another element, forms what is called an alkaline base, while a larger proportion of oxygen produces the substances called acids. Other proportions of this gas with other elements produce neutral bodies (those which are neither acid nor alkaline), of which the most remarkable instance in nature is *water,* a mixture of oxygen and hydrogen. A number of other combinations, under the name of *salts,* also derive their important properties, and many of their most interesting peculiarities, from the presence of oxygen.

16 *Combustion.*—The phenomenon of combustion is one which it is

chiefly the province of the chemist to consider in reference to the various elementary bodies, but it is also very essential that we should have a general idea of its nature, in order to comprehend the mutual relations of light, heat, and chemical action. The combinations of oxygen with other substances are attended with an alteration of volume and the evolution of heat, and often, but not always, by a considerable amount of light; and in common language, when a body combines with oxygen, it is said to be burned, and instead of undergoing oxidation, is said to suffer *burning*, while a body which can combine with oxygen and emit heat is called a *combustible*. It is important to remember, that no loss whatever of ponderable matter occurs in combustion, and that the matter formed may always be collected and thus proved to have the weight of the oxygen gas added to that of the combustible, which has either been reduced to an ash, or has entered into new combinations during the process. There is no such thing as annihilation discoverable in nature.

17 *Nitrogen, Hydrogen, and Chlorine, with their Combinations.*—*Nitrogen gas* is a singularly inert substance. It is tasteless and inodorous, and is lighter than atmospheric air, of which it forms four-fifths, and in which it seems chiefly to act as a diluting medium. Forming so large a part of our atmosphere, it is necessarily a very important and abundant material, but it mixes with few elements, and its properties are chiefly negative. In many respects, it is remarkably contrasted with the third highly important gas, *hydrogen*, which, indeed, has been compared to metals, in its relation to other elements, although it is the lightest substance known in nature, and is highly inflammable.

Water—a substance universally distributed at the Earth's surface, and present there in large quantities—is the result of the combustion of hydrogen and oxygen gases. It is eminently a neutral body, and is to a remarkable extent capable of dissolving various proportions of other substances—a quality which is well illustrated in the composition of sea water, whose density is greater than that of pure water, by the addition of 3½ per cent. of saline matter. It is probable that, at high temperatures, water is capable of holding in solution a portion of almost every substance in nature. It is chiefly the remaining gas, *chlorine*, combined with *soda*, which makes up the saline matter present in sea-water.

18 *Non-metallic Solid Elements.*—Amongst the substances presented in a solid form under ordinary atmospheric conditions at the Earth's surface, *carbon*, *silicon*, and *sulphur* are highly important, extremely abundant, and widely distributed. They are all of them also without those peculiarities which characterize *metals*, in the ordinary acceptation of the term. It will be as well to describe the more usual forms of these elements.

Carbon occurs in three very different forms in nature, being crystallized in the diamond; existing in a state of partial crystallization, but of a very different fundamental form, in graphite or plumbago (the common black lead); and in a very different state again in the varieties of mineral coal. It appears to be quite infusible at any temperature, or under any circumstances to which it has yet been exposed by the chemist, and seems to offer itself under this variety of aspects, according to the structure of the substance from which it is derived, and the mode of its preparation, when obtained artificially.

Carbon is abundantly present in all organic substances, and is a principal ingredient in the carbonates, of which limestone (carbonate of lime) is the most widely distributed, and the largest in quantity.

Sulphur is likewise an elementary substance, occasionally found native and pure, but more commonly combined with other elements. This is especially the case with regard to the most important metals, which are, with few exceptions, found associated with this substance. The metal *arsenic*, and another rare metal called *selenium*, exhibit very remarkable analogies with sulphur in their mixtures with metals.

Silicon is the name given to an elementary substance derived by removing its oxygen from pure silica, which in the state of flint or siliceous earth is one of the most abundant of all the matters that compose the Earth's crust. This mineral constitutes sand, all the different varieties of sand-stone and quartz rock, and, combined chemically with alumina, it forms a very large proportion of all clays. In its pure and elementary state it is of little interest, but in consequence of the number and importance of its combinations, it is beyond all comparison the most remarkable of the non-metallic elements. Combined with lime, potash or soda, magnesia, or alumina, and often with iron, it forms nearly all the other mineral ingredients of granite, mica-slate, volcanic rocks, shales, sandstones, and various soils—in other words, of all rocks, with the exception of pure limestones.

19 *Metallic Elements the Bases of Earths.*—The metal *calcium* mixed with oxygen (with which it combines so readily as not to be preservable, if exposed in contact with any known substance containing that gas) forms the substance called *lime*, and this again combined with carbon and an additional supply of oxygen (carbonic acid), is the ingredient of all marbles and limestones, including under that name chalk and other calcareous bodies of whatever kind. Combinations of other elements with lime are also abundant in nature, and of these sulphate of lime (gypsum or alabaster) is one of the most interesting.

Alumina, derived from an obscure metal, just as lime is derived from calcium, is rarely met with in nature, except as a very hard and precious mineral, called the oriental sapphire, which exhibits its true crystalline form. It is as silicate of alumina or clay that this material is most interesting in reference to the Earth's crust. In that form, however, it is universally and abundantly distributed.

Soda and *Potash* are two other substances which are very widely distributed; the former in sea water with chlorine, the latter in nitre (*saltpetre*). *Magnesia*, in like manner, is very plentiful, although the quantity is not so great as in the case of some other substances which may be regarded as proximate elements.

20 *Metals.*—*Iron* is the only metal which is at once so universal and so abundant as to be worthy of a rank among the principal ingredients of the globe. It is not found native in the Earth, though fragments are met with on the surface, containing this metal in association with other metals, but its ores are numerous, and its presence is everywhere recognised. It is quite unnecessary to define and describe a substance so universally known.

These various substances, the remaining elements, and numerous combinations of these and other elements, amounting, however, in all to a comparatively small number, are mixed together in certain definite proportions, and thus form what are called *minerals*, groups of which in mass are designated *rocks*. Minerals, in most cases, are capable of assuming definite forms, and become crystallized into certain recognisable shapes, the study of which, and of their relations with each other, forms the basis of the science of mineralogy. The consideration of those masses of minerals which we have described as rocks, the earths, clays, limestones, sandstones, &c., the various kinds of granite and slate, and all other great and widely-spread collections of like minerals, forms one department of geology, and is more immediately interesting in the study of physical geography.

21 *Mutual Action of various Forms of Matter.*—Reverting to the observations made in the beginning of the present chapter, it will be understood that the division of all matter present at the Earth's surface into three parts—namely, solid, fluid, and aerial—has its origin in certain conditions of temperature and certain chemical combinations. It is not, as we have now seen, an *essential* condition of matter that there are these various states, it is rather what may be called an *accidental* condition, but at the same time one particular state seems much more consistent than any other with the known properties of some of the elements, and also of some of their combinations. These various conditions, however, involve many modifications, chiefly mechanical, and the fact that air and water are capable of retaining small quantities of each other, and of various elements in solution and suspension,

without chemical change, causes some very important and highly interesting results. The crust of the Earth is greatly affected by the passage over it of air and water; these latter substances also greatly affect each other, and the whole mechanical structure of the crust is, in fact, due to the action of air and water, and air mingled with water, as modified by the changes of temperature resulting from the partial incidence of the sun's rays on the surface, and the more or less favourable condition of the atmosphere for transmitting light and heat, as well as of the Earth's surface for receiving them. Thus, it is that METEOROLOGY and HYDROLOGY become part of Physical Geography, and that the sciences relating directly to air and water require to be considered as portions of a more general science, whose object it is to describe general terrestrial phenomena. Thus also it is that CHEMISTRY is to a certain extent required for the same end, and that the laws affecting those forces which modify the material elements, must be in some measure explained and understood, before we can proceed to consider either the surface or structural phenomena of our globe.

22 *Terrestrial Magnetism.*—There is yet one more subject to be considered before passing on to the material phenomena of the globe. The researches of natural philosophers, chiefly of our own day, have brought to light a vast group of facts concerning the magnetic condition of the Earth, and have shown that which is now designated 'terrestrial magnetism,' must be regarded as one of the most important, if not absolutely the most important, of all the imponderable agents. We have already alluded to the phenomena of magnetism, commonly so called, and have said that the tendency of a magnetic needle to arrange itself in a certain direction, is connected with a subject of great extent and high interest. The Earth, in fact, exhibits a certain amount of magnetic force, and this is manifested at the surface by three classes of phenomena: varying *intensity* of the attraction; varying *declination,* the needle not always pointing to the same spot or pole on the Earth's surface; and varying *inclination,* or amount of departure of the needle from the horizontal plane. This latter variation is called the *dip* of the magnetic needle, and the declination is commonly spoken of as the variation of the compass. In other words, when a compass is referred to, in different parts of the Earth, or at distant periods, the needle will not be found always to arrange itself so quickly in its position of rest; it will not always point to the same point, and it will not, if suspended, freely repose in a horizontal plane, or at the same angle to the horizon. In illustration of this, it may be mentioned, that while in the year 1657, the needle pointed due north in London, this was not the case in Paris till twelve years afterwards, notwithstanding the small difference in longitude between the two cities. At the present time, the whole of Europe, except a small part of Russia, has west declination, while in Asia the declination is east.

But the most remarkable fact with regard to this constant shifting of the direction of the needle, is that there is an hourly change of position dependent on the apparent course of the sun and the lapse of time between the observations. The hour of the day may in this way be known between the tropics, and the movements of two small bars of magnetized steel suspended from a thread, even if they are suspended at depths beneath the Earth's surface, will measure accurately the distance which separates them. There are also parts of the Earth where the mariner, who has been enveloped many days in fog, seeing neither sun nor stars, and having no means of determining time, may know with certainty, by an observation of the magnetic inclination, whether he is to north or south of the port which he desires to enter.

The hourly changes of declination of the needle seem to be governed by the sun, while that luminary is above the horizon of any spot, but they also have reference to the actual position of the spot on the globe, and its distance from the magnetic poles. Throughout the northern hemisphere the mean movement of the north end of the needle from 8½ A.M. to 1½ P.M. is from east to west, and in the southern hemisphere, at the same time, from west to east. Thus, along a line near the equator there is no horary variation in declination.

The name of *magnetic poles* has been applied to those points on the Earth's surface where the horizontal force disappears. Of these there are two in each hemisphere, not far removed from each other, or from the true poles of the Earth, but unequal in the amount of their attractive force. The focus of greatest intensity in the northern hemisphere is in North America, near the south-west shores of Hudson Bay, in 52° N. latitude. The corresponding weaker focus is in Siberia, about 120° E. longitude from Greenwich.

It is known that the forces which attract the north end of a magnet and repel the south end, preponderate in the northern hemisphere, while in high latitudes, in the south hemisphere, the converse is the case. There is, therefore, in addition to the line of no declination, near the equator, another line of no preponderance of the northern or southern force, and it is found that both lines are extremely irregular.

The intensity of the magnetic force is measured by examining the oscillation of a suspended needle, and is determined with very great accuracy. The intensity increases towards each pole, and thus we have a line of least magnetic intensity near the Earth's equator, in addition to those lines already mentioned, and quite distinct from them.

Intimate relations have been discovered between the state of electricity of our atmosphere and the magnetic condition of the Earth, and it is known that while a conductor of electricity is rendered magnetic by the passage of an electric current through it, so also magnetism gives rise by induction to electric currents. The identity of electricity and magnetism is thus fully made out.

The important discoveries of Faraday on the condition of matter with regard to magnetic influences—magnetic force affecting all bodies as necessarily and directly as the force of gravitation,—has given new interest to this subject. According to the result of his experiments, all substances arrange themselves into two great divisions—*the magnetic*, in which the substances tend to place themselves parallel to the direction of the magnetic needle, at the spot where the experiment is performed; and the *diamagnetic*, where the tendency is to assume a direction at right angles to that of the needle.

By far the greater portion of the materials which compose the Earth's crust belong to the latter, or diamagnetic class; for even as respects the rocks and mountains, the quantity of magnetic matter needed to counteract the diamagnetic tendency is very large, and the ocean, lakes, rivers, and atmosphere exert their effect as diamagnetics, almost uninfluenced by any magnetic matter. Mr. Faraday has suggested the possibility of magnetism being, in fact, generated in the atmosphere by light proceeding from the sun, and passing rapidly through the air, but he wisely suspends any theoretical considerations until experiment has given a sufficient groundwork for them. However this may be, there can be little doubt that for all practical purposes we must regard the magnetic force as resident only on the surface, or rather just within the oxidised crust, which is all that we actually know of our globe. The Earth is not, as was once imagined, an inert mass, having, by some unimagined means, a peculiar power to attract iron towards its two poles of rotation. It is a mass of matter, every part of which is affected by magnetic force, and which is, throughout its external crust, hard and immoveable as that may seem, exposed to changes and modifications of the most extraordinary kind, and of great extent.

CHAPTER III

METEOROLOGY.

23. Constitution of the atmosphere.—24. Its chemical condition.—25. Its chief importance in Physical Geography.—26. Its relation to light generally.—27. Twilight.—28. Mirage.—29. Colour.—30. Atmospheric meteors exhibiting colour.—31. The phenomena of sound.—32. Motion of the air—Winds.—33. Land and sea breezes.—34. Trade winds.—35. Monsoons.—36. Hurricanes.—37. Relations of the atmosphere to water.—38. Dew.—39. Mists and fogs.—40. Clouds.—41. Rain.—42. Distribution of rain.—43. Snow.—44. Glaciers.—45. Hail.—46. Climate, and distribution of heat.—47. Conclusions.

CONSTITUTION of the Atmosphere.—We proceed now to consider that portion of the material universe present in an aerial form at the Earth's surface, and which has long been known under the name of *atmosphere.* The atmosphere is highly elastic, and therefore more dense near the Earth's surface than in its upper portions, where there is less pressure; but notwithstanding its great elasticity, there can be no doubt of its terminating absolutely at a small elevation compared with the magnitude of the Earth. The real extent of this gaseous veil has not indeed been very satisfactorily determined, and has been variously estimated at from forty to a hundred miles; but as the diameter of the Earth is eight thousand miles, the largest estimate does not assume it to be more than one-fortieth part of the radius, and there is no reason to suppose that it is nearly so much.

The weight of the whole atmosphere can be accurately determined, and the degree of pressure at any point is also a fact which offers little difficulty in determining. By depriving of air the closed upper extremity of a tube filled with mercury, which opens below into a cistern also full of mercury, the pressure of the whole column of the atmosphere may be measured against that of a column of mercury, and thus the pressure is found to be equivalent to about fifteen pounds on every square inch of surface.

The constituents of the atmosphere are as follow. Of every 10,000 parts of air in the ordinary state with regard to moisture, there are—

Oxygen	2,100
Nitrogen	7,750
Aqueous vapour	142
Carbonic acid gas	4
Carburetted hydrogen	4
	10,000

There is also a trace of ammoniacal vapour.

It was formerly supposed, that in whatever part of the Earth it is taken, at whatever depth or height above the mean level of the surface, or under other peculiar circumstances, the constitution of the atmospheric air was exactly the same. Although this is not quite true, it is very nearly so, the quantity of oxygen varying slightly, but perceptibly, in different seasons of the year, and over the sea, or in the interior of continents. So much change by oxidation is constantly going on at the Earth's surface, that it would be strange if this were not the case; but the absolute quantity of this gas compared with the surface and the materials exposed to its action, is far too great for the change to be readily perceived.*

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* It may be interesting to repeat here the different localities from which the atmospheric air has been chemically examined, to show how little the proportion changes. The air from the Alps was analysed by the younger Saussure; from Spain, by De Marti; from France and Egypt, by Berthollet; from England and the coast of Guinea, by Davy; from the Peak of

In addition to the materials already mentioned, there are also traces of ammoniacal vapour and even of some other gases in the atmosphere; but these, although important in their influence on organization, are not to be considered as affecting the general physical condition of the air. It has also been supposed that the atmosphere contains, diffused through it, minute portions of the vapours of all those substances with which it is in contact, even including earths and metals. Although, however, unknown ingredients may be occasionally mingled with the atmosphere and impart to it deleterious properties, such ingredients being of too subtle a nature, and present in too small proportion, to be discovered by our imperfect instruments, it yet appears that a limit exists to the production of vapour of any tension by bodies placed in such a medium as the atmosphere, and that beneath such limit they are perfectly fixed.

24 *Its Chemical Condition.*—Two views have been entertained of the nature of the union that exists among the elastic bodies forming our atmosphere. It has been generally supposed to be a chemical compound, because the proportions are very nearly fixed, and the ingredients do not tend to arrange themselves according to their different specific gravities. It is, however, more probable that the mixture is, after all, mechanical, the various elastic fluids not having any attraction or repulsion towards each other beyond that of the simple action of the law of gravitation, and each of the ingredients exerting its own separate pressure, and behaving as if it were itself free, and formed a distinct atmosphere.

The most important and valuable investigations in the science of meteorology, have been founded on the assumption that there are two distinct atmospheres, one of dry air, and the other of aqueous vapour, and that these are mixed mechanically together; and also on the conclusion that the relations of these to heat are different, and their states of equilibrium incompatible with each other. Thus are produced those changes of condition consequent, as we know, upon changes of temperature, and also those other changes resulting in what is called *climate.*

25 *Its chief Importance in Physical Geography.*—The atmosphere may be chiefly regarded as important in Physical Geography in its relations with light and sound; with heat, as the means of distributing temperature; with water, as the means of distributing moisture over the Earth; and with electricity, as connected with the mode of action of this force in all its various forms. The motion that takes place in the atmosphere, and which we denominate *wind,* is thus a matter of vital interest, since it aids in these distributions, and affects also very directly many operations of man. The optical and acoustical phenomena of the air being, to a certain extent, independent of its motion, though not uninfluenced by it, may first be considered. We may then study the phenomena of the winds, and afterwards proceed to consider some points connected with the distribution of heat and water.

26 *Its Relation to Light.*—In its relations to light, our atmosphere plays a very important part, and greatly affects the action of several forms of the imponderable force; and whatever its origin or true nature may be, it is capable of transmission through certain bodies, thence said to be *transparent,* of which the atmosphere is one.

It is found that in being transmitted or passed through a transparent body, a change of direction of the ray of light takes place whenever the substance through which light passes becomes of different density, or when light passes from one medium to another of different density. Thus, when a stick is placed in water, and is not vertical, it will appear to an eye looking down

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Teneriffe, and near the summit of the Andes, by Humboldt; and from the still loftier elevation of 22,000 feet, (attained in a balloon,) by Gay Lussac and Thenard; and all these gave results approaching as nearly as possible to each other. The observations of Lewy are those referred to as showing a slight difference in different parts of the Earth.

upon it as if it were bent, for the water is more dense than the air, and the body is seen only by means of the rays of light which proceed from it; and thus, also, if light pass through air of different density, the rays are bent at an angle or curved. A part only of the light, however, is transmitted, part of it being actually lost, part of it reflected, and a part dispersed. It is important to remember that, in proportion as light passes through a greater thickness of matter, as for example, of air of varying density, it becomes less and less in quantity, being gradually absorbed, dispersed, and reflected.*

It is usual to speak of the bending of light in its passage from one medium to another of different density, under the term *refraction*, while the throwing back of light from a surface is called *reflexion*. A ray falling on a body is said to be *incident*. The part transmitted is *refracted*, and that thrown back, *reflected*.

The course of a ray of light in its progress to the earth is, therefore, as follows:—The ray falls on the uppermost limits of the atmosphere, and meets there an elastic transparent fluid: at this point it is turned aside or *refracted*, a small part of it being, however, reflected back into space, a part dispersed, reflected, or distributed into the surrounding atmosphere, and a part absolutely lost. As it proceeds through the air towards the Earth, it passes continually into a denser atmosphere, because the pressure increasing, and the air being elastic, the dimensions diminish, and at each instant the ray becomes therefore more and more deflected, while more and more of it is absorbed, and more is also dispersed and reflected. The portion that reaches the Earth varies in quantity according to the extent of atmosphere passed through, and its density, and is therefore not constant; but whatever the amount be, this portion is reflected back from the surface of opaque bodies, or transmitted, with still further loss, through transparent ones, and so again and again till it is completely dispersed or destroyed.†

Diminished splendour, and the false estimate we make of distance, from the number of intervening objects, lead us to suppose the sun and moon to be much larger when in the horizon than at any other altitude, though their apparent diameters to the eye when measured are then somewhat less. These and a number of other effects are results of refraction and the partial loss of light in passing through a great thickness of atmosphere.

In consequence of the dispersion of light by means of the atmosphere, we obtain all those varieties of half shade which alone enable us to make use of organs of vision constructed as ours are. If it were not for this, we should constantly have either full broad and dazzling light, or deep black shadow and impenetrable darkness. The objects from which light is emitted are few, and, with the exception of the sun, are rarely available, except by artificial means, so that in countries where the sun is often long absent, or where the clouds obscure its face during a large part of the day or year, the inhabitants would, in the cases alluded to, be in total darkness. A large quantity of light being, however, dispersed and reflected from particles of vapour in the air, there can hardly be found at any hour of the night, or at any season, a total absence of light, and there are no sudden and abrupt transitions to affect our delicate organs of vision.

27 *Twilight.*—During a fine, clear, calm day, in our northern latitudes, it may be observed, that as the sun approaches the horizon, the sky in the west assumes a yellow or red tint; towards the zenith, or directly overhead, it becomes whitish, and the sky is less clear; until just as the sun has fairly

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[*] See *ante*, p. 76.

[†] The quantity of light that passes through the atmosphere in different states may be thus estimated:—Of 10,000 rays falling on the surface of the Earth, 8123 arrive at a given point if they fall perpendicularly, 7024 if the angle of direction be 50°, 2831 if it be 7°, and only five rays arrive through a horizontal stratum. In consequence of so large a proportion of light being sometimes lost in passing through the atmosphere, many celestial objects may be altogether invisible from a plain, and yet be visible from elevated situations.

sunk below the horizon, a red colour is seen in the east opposite to the setting sun. This is the commencement of the phenomenon called *twilight*, and is owing to the existence and properties of the atmosphere, and chiefly to the light being reflected from its higher portions. It depends, however, on the position of the Earth with respect to the sun, and also the condition of the atmosphere at the time, how long this phenomenon shall continue; since, in the fogs of winter, darkness comes on almost immediately after sunset, while, on a clear summer evening, the broad light of day continues for more than an hour little diminished. A similar phenomenon of twilight occurs in the morning before sunrise.

Investigations concerning the absolute limits of our atmosphere have been greatly assisted by careful observations on the duration of twilight, but the subject is one of great intricacy, and the results which have been hitherto obtained are not absolutely conclusive.

28 *Mirage.*—It is not only the rays of light that proceed from a luminary without the Earth, but also those emanating or reflected from bodies at and near its surface, that are refracted by the unequal density of different parts of the atmosphere. The phenomenon of ordinary refraction, as it occurs in fluids of equal density throughout, is exceedingly simple, of whatever kind the fluids may be, when once the principle of refraction is understood; but this is not the case with some curious appearances connected with unusual and irregular refraction producing optical illusions, and not unfrequently assuming all the appearances of direct reflection. The word *mirage* has been applied by the French to such phenomena, and as there is no satisfactory English translation, we must be content to adopt it.

The illusions of mirage differ according to circumstances, and they are sometimes exceedingly strange and almost startling in their character, presenting an image of what really exists, but is entirely out of the range of ordinary vision. Sometimes, also, they exhibit parts of objects, broken, distorted, and out of place; sometimes they confuse in a singular manner the true outlines of objects, and occasionally they present a gorgeous and fairy-like spectacle—superb palaces, with their balconies and windows resting on the bosom of the broad ocean, lofty towers near them, herds and flocks grazing in wooded valleys and fertile plains, armies of men on horseback and on foot, with multiplied fragments of buildings, such as columns, pilasters, and arches. All these may be seen again repeated in the air above, and fringed with red, yellow, or blue light.

Phenomena so striking can be explained only by a reference to the condition of the atmosphere when in an unusual state with regard to moisture as well as density, and they may be conveniently arranged under one or other of the three following classes: vertical reflection, lateral reflection, and suspension.

The most simple example of vertical reflection is that often observed in hot sandy deserts, and occurring after the soil has become heated by the presence of the sun. In such cases, the prospect seems bounded by a sheet of water, and underneath each object, as the villages which in Egypt are generally built on small eminences, the apparent reflection is seen as if in water. A singular effect of this kind is described as having been noticed in India, where Captain Maunday states, 'A deep, precipitous valley below us, at the bottom of which I had seen one or two miserable villages in the morning, bore in the evening a complete resemblance to a beautiful lake. The vapour, which played the part of water, ascending nearly half-way up the sides of the vale, and on its bright surface trees and rocks were distinctly reflected.'

In horizontal reflections the image is presented sideways. In this manner Dover Castle has been seen from near Ramsgate, as if an intervening hill, which under ordinary vision cuts off a part of it, were actually removed; and in this way, too, the French coast has been seen distinctly, and in all its details, from near Hastings, although the distance is sufficiently great to render it invisible by ordinary refraction.

The phenomenon of suspension is not less remarkable, and is called in sea language, *looming*. It consists in the representation of an object immediately above its true place, either in its true position or reversed. Thus, Captain Scoresby describes that he on one occasion distinctly recognised his father's ship at sea, by its inverted image in the air, although the distance between the two ships was as much as thirty miles, and the ship was therefore far below the horizon of that from which it was observed.

All these phenomena, and their different modifications, depend on the different density of the lower strata of the air, and as this difference of density may be occasioned both by heat and moisture, and as heat may be reflected from a mountain side as well as from the horizontal surface of a plain, and from the sea as well as from the land; and further, as contiguous vertical columns of air, as well as horizontal strata, may be of different densities, it is easy to understand why mirage may be seen in very different situations, and why it presents such varied appearances. It will also be evident that any cause which re-establishes the equilibrium of density in the different portions of the air must cause the illusions of the mirage to vanish. Calm in the atmosphere is almost essential to the phenomenon in question, and it has been remarked that this perfect calm is often the precursor of a tempest.

29 *Colour.*—The ray of white light proceeding from the sun, and whose course we have traced through the atmosphere, has been found to consist, in reality, of several rays, some of which communicate to our eyes the notion of various colours, while others seem chiefly important in producing heat or chemical action. It is found, also, that these rays are differently affected by passing through, or being reflected from the same substances, some being more readily absorbed and lost than others. Thus, the impression on our senses in looking through the clear atmosphere, is that of blue, while the setting sun communicates red or golden light to clouds, according to the circumstances under which the light falls.

The colours which, being combined, make white light, are three, and are called blue, red, and yellow, but several well marked modifications of these exist, and it is usual to speak of seven primitive colours—viz., red, orange, yellow, green, blue, indigo, and violet.

All substances known, however opaque, allow some portion of light to pass through them, and all, however transparent, absorb and destroy some rays. The colours of bodies are derived from their power of absorbing certain rays more readily than the rest, and thus giving forth light, which, instead of being a mixture of colours in the proportions of white light, have some colour in excess. the idea of which they communicate to the eye. When light also passes through a transparent medium, such as a prism, a glass sphere, or a drop of water, it becomes decomposed, and in this way are produced some of the most striking meteoric effects in which colour appears. Bodies that reflect all the rays in the same proportion appear white, those that absorb all are black; a violet reflects the violet rays alone, and absorbs the rest; while a leaf reflects the blue and yellow rays, absorbing the red, and produces by a mixture of the two the compound colour known as green. Very careful observation has shown that there are dark lines in the image of the sun received on a screen after the transmission of a ray of light through a prism, and these by their permanence and uniformity appear to show that certain rays are absorbed in passing from the sun, or perhaps in traversing the solar atmosphere.

30 *Atmospheric Meteors exhibiting Colour.*—The *rainbow*, one of the most striking of the common but occasional meteors, is the first that requires notice. It is a circular arch of variously coloured light, visible in the heavens when the sun or moon is shining, and when at the same time a shower of rain is falling,—the spectator being placed with his back to the sun, and observing the falling rain. Besides the principal bow, a second bow with inverted colour is often seen outside the principal one. Both consist of concentric bands of the prismatic colours, arranged as they have been described to occur in the solar spectrum. The lower edge of the interior bow is violet.

It is not very difficult to comprehend generally the cause of the rainbow. A ray of sunlight entering a drop of water as it is falling to the earth is refracted as it enters, and the refracted ray is subsequently reflected from the inside of the drop on its opposite side, and then emerges and proceeds towards the eye of the spectator, placed as has been described. But the rays of colour being refracted to different points, and becoming a line of coloured light as they issue from the drop, a part only will really reach the eye of the spectator, and from one drop he will see one colour. The same will happen with all the other drops, and the eye will only be sensible of a band of coloured light having an apparent breadth about equal to four and a half times the sun's apparent diameter in the case of the inner bow, and an outer band about half as large again.

The appearance sometimes observed around the sun and moon, and termed *halo* or *corona*, is caused by the refraction of light by particles of water floating in the air. *Parhelia*—repetitions of the sun near the true place of that luminary, and *athelia* or false suns, are referred to the refraction of light by floating prisms of ice. These and a number of rarer results of the action of those laws which affect light, produce their effect in consequence of the peculiar condition of our atmosphere, its occasional and irregular contents, and its unequal density.

31 *The Relation of the Atmosphere to Sound.*—If the atmosphere were removed, and our organs of hearing remained as they now are, a death-like silence would appear to us to pervade nature; for all sound is connected with vibrations of particles of the air, producing waves throughout the whole mass, though each individual particle does not move far from its state of rest. The appearance of a field of ripe corn when agitated by wind, offers a good illustration of the condition of the atmosphere when transmitting sound, the only difference being, that each ear of corn is set in motion by an external cause, and is uninfluenced by the motion of the rest; whereas, in air, which is compressible and elastic, when one particle begins to oscillate, it communicates its vibrations to the surrounding particles, which transmit them to those adjacent, and so on continually.

The velocity of sound is uniform, and quite independent of its loudness; but whatever increases the elasticity of air, must accelerate the rate of the vibration, so that sound travels faster in warm weather than in cold. The speed at the temperature of 62° Fah. is 1143 feet per second, whereas at freezing temperature, sound only travels 1089 feet in the same time. It is an interesting fact that the rate of speed of sound is faster than would appear from theory, unless the result of the compression of the air in the transmission of the wave is taken into account. It has been already said that compression of an elastic fluid produces heat, and we have just seen that heat quickens the rate of transmission. Thus the actual rate at which sound travels is about one-sixth greater than it would have been, if the temperature remained unaltered during the compression of the atmosphere.

The transmission of sound, therefore, as well as the ten thousand other changes going on about us, are themselves engaged in originating still further changes, and calling into action powers and forces at first little suspected.

All fluids and solids transmit sound, and most of them far more rapidly than air. Water, for example, conveys vibrations of this kind four times, and some kinds of wood nearly seventeen times, as rapidly as air. Still, air is the only means on which we can depend, for without this, our auditory apparatus would be useless, or only available by the actual contact of material bodies in the solid or fluid state.

32 *Motion of the Air.—Winds.*—So long as the density of the air remains the same, there is nothing to disturb the equilibrium of the atmosphere, but if from any cause the equilibrium is disturbed, a movement results, which we call *wind.* If, for example, at any point of the Earth's surface the temperature is increased and the air above it heated, a displacement occurs, the warm air rising, and cold air rushing in from all sides to restore the balance. These

currents of air play a very important part in nature. They purify the air ot towns; they modify and improve extremes of heat and cold; they disperse clouds, and they assist, by the distribution of pollen and seeds, and by a constant agitation of the different parts of plants, in preserving vegetation in a healthy state, and ensuring its continuance.

Winds are generally denominated from the quarter from which they blow. Thus, we speak of a north-easterly wind or a south wind, but there are also names given to some winds that are locally prevalent, or that exhibit any peculiar characteristics. Such are the trade winds, the monsoons, and others.

The wind blows not only from various quarters, but with every degree of force and rapidity, from the most gentle zephyr to the most destructive hurricane. The different kinds of winds in respect of quickness and force are spoken of under the terms breeze, gale of wind, and tempest or hurricane, respectively.

The direction of winds is determined by reference to an arrow or weathercock placed on an elevated position, and where there are no adjacent buildings at so great an altitude to disturb the true direction of the current. The intensity of force is measured by an instrument called an *anemometer*, the principle of which is that of a small windmill, whose sails are moved more or less rapidly as the wind is more or less powerful.

However apparently various the causes of winds may be, they are almost all referrible more or less directly to changes of temperature. The Earth is constantly presenting a different portion of its surface to the direct rays of the sun, and is consequently exposed perpetually to alterations of temperature. These all affect the atmosphere, and produce an infinity of minor currents, influenced, however, by certain main currents, consequent upon the general regularity of the change undergone.

The winds which it is important to notice, as belonging to a general view of physical geography, are these: the land and sea-breezes, which occur daily on the coast and in the islands in tropical regions, certain periodical winds prevailing in some parts of Europe, some irregular winds observed in districts offering remarkable physical features, the trade winds, the monsoons, storm winds, hurricanes, and whirlwinds. Those irregular winds which blow from various quarters in temperate latitudes are not sufficiently referred to general principles to admit of description in this place.

33 *Land and Sea-breezes.*—The winds called *land and sea-breezes* are derived from the unequal action of the sun on the land and water, combined with the tendency of the atmosphere to preserve a state of nearly uniform density. During the day, in hot countries, the steady shining of the sun, especially when nearly vertical, heats the land much more than the adjacent ocean, and thus the atmosphere above the land becomes more rarefied, and from about nine A.M. the air from the sea flows towards the land, to occupy the partial vacuum produced. As the heat of the land goes on increasing, the force of the breeze increases also, and this continues till two or three, P.M. After that time, the temperature of the land diminishes, decreasing much more rapidly than that of the water, so that about sunset the breeze from the sea ceases. During the night, the sea and the air over it retain their temperature, but the land and overlying air become cooler, and the breeze then sets in from the land, the warmer and lighter air being again displaced by the cooler and heavier. This breeze from the land augments in force till near sunrise, when the temperature of the earth begins to increase once more, until about nine A.M., when the sea-breeze sets in. These breezes are not confined to the coast, as they converge and diverge in every direction, and extend far inland, but they must still rank as local phenomena.

There are some periodical winds lasting for very limited periods, and occurring in various parts of the Earth. In the eastern part of the Mediterranean, for example, a current sets in from the north-east, and blows every day from about the middle of July till the end of August, commencing at about nine A.M., and dropping at sunset. Similar winds blow in Spain and also in Asia from the east, but are of shorter duration. Such winds are probably caused by the rarefaction of the air under the tropic of Cancer, in consequence of the heat of the sun at the season during which they blow.

The most important of the atmospheric movements observed and referred to regular laws occur within a zone, whose general limits are the thirtieth parallel of latitude above and below the equator; although beyond these limits, some of the prevailing winds which there take their origin are often found to extend.

34 *Trade Winds.*—There are two regions in which the *trade winds* prevail; the one is north of the equator, reaching from latitude 10° north to the tropic of Cancer, and extending in the West Indies to near 30° north latitude, the other commencing a few degrees south of the equator, and extending generally to the tropic of Capricorn; but in the Pacific Ocean, reaching a little further to the south. Between these regions is a zone of variable winds and calms.

The zone of variable winds and calms, situated close to the equator, is a convenient point of departure in describing the periodical and regular winds. Although generally characterised by calms and light westerly breezes, sudden storms and squalls are not unusual, and vast quantities of rain fall there. The general result of the rotation of the Earth on its axis, from west to east, and the greater influence of the sun near the equator, cause the atmospheric covering of the globe to be, as it were, left behind, producing apparent winds near the equator. These, and the polar and equatorial currents that set in, and affect chiefly, and at first, the higher parts of the atmosphere, appear to produce the singular zone just referred to. It is situated entirely north of the line, owing, no doubt, to the peculiar form of the land in the northern hemisphere, and the great preponderance of land there.

The trade winds are perpetual winds occurring in the open tropical seas, north and south of the zone of calms, and are so called because they greatly promote navigation and trade. To the north of the equator, these winds blow in the eastern parts of the ocean from the north-east, but further to the west they become more easterly, and sometimes even blow from a little south of east. South of the equator they blow in the eastern parts of the ocean from south-east, but become more nearly due east towards the west. They blow with less force and steadiness in the eastern than in the western seas, and are only experienced at a distance from land and in the open ocean. They are generally stronger in the hemisphere where the sun is not vertical, and are also there less easterly. The weather is generally fine when the trade winds are blowing, but, as has been already observed, the intermediate belt of sea is remarkable for the quantity of rain that falls there.

The trade winds occur both in the Atlantic and Pacific Oceans, but vary considerably both in extent and force in these two great divisions of the water.

In the Atlantic, they are found to have a wider range on the American than on the European side, and on that side they blow from due east, while near the Old Continent the direction is north-east. Of the two regions affected by these winds, the northern is less regular than the southern, and towards its northern boundary is less boisterous and capricious. The latter, or southern region, also ranges much further north, commencing a little north of the equator, so that the northern district of the trades is even sometimes encroached on by it, and the winds meet.

In the Pacific, the trade winds are by no means so well determined as in the Atlantic, nor are they so extensive in proportion to the much greater breadth of open sea, or so much to be depended on. They appear to blow permanently only over that part of the ocean extending from about the meridian of the Galapagos to the Marquesas, or from longitude 91° to 130° W., afterwards becoming periodical winds, or monsoons. In the Indian Ocean, from the coast of Madagascar to the shores of Australia, the south trade winds prevail, but the northern do not exist. As in the Atlantic Ocean, the southern perpetual winds extend north of the equator, when the sun is in the northern hemisphere, having been met with as far as 3° 30′ N. lat. in the month of July; but in the opposite season, they recede to one or two degrees south of the line. The north-eastern trade wind is described as being more regular than in the Atlantic, and its northern boundary less variable. The region of calms in the Pacific is little visited, and less known. It is certainly north of the equator, but probably nearer to the line than in the Atlantic.

The boundary of the trade winds in the temperate zone, in both hemispheres, and in both oceans, varies with the seasons—the difference being considerable: and thus there occur regions, several degrees of latitude in width, alternately exposed to the sway of trade winds and of variable winds. The actual termination of the zone of trade winds is generally marked by a sudden change of wind. This region of variable winds in the Pacific, and especially in the southern hemisphere, is generally much more uniform than in the Atlantic.

The trade winds are confined to the ocean, but regular and constant easterly winds also occur between the tropics in some countries, which probably owe their origin to the same cause. Such winds, however, do not extend beyond extensive level plains. Examples are seen in the easterly wind which blows all the year over a great part of the Sahara, or Desert of Africa, and a similar wind always blows on those vast plains of South America which are drained by the Amazon, and on those in the lower course of the Orinoko.

The cause of these winds is generally considered to be the constant rarefaction of the air between the tropics, where the sun exerts so much more power than in the temperate and frigid zones, and the consequent rushing in of currents of cold air, from the north and south, towards the equator. If the winds moved with the rapidity of the Earth, the currents would of course be north and south, but as this is not the case, and the Earth moves far more rapidly from west to east, the winds are left behind, and appear to blow from other points. Thus, they blow from the north-east in the northern hemisphere, and from south-east in the southern, while near the equator, and where influenced by land, they occasionally blow from due east, or nearly so.

35 *Monsoons.*—These winds differ from the trades, in being only periodical, while the latter are perennial. They occur chiefly in the Indian Ocean, but prevail also in the seas between Australia and China, which may, indeed, be considered a portion of the Indian Ocean. They are produced by the peculiar conformation of the land in that portion of the Old World, and by the predominance of land there, combined with the difference of temperature constantly existing between it and the sea in its vicinity.*

The monsoons nearly occupy the place of the northern trade winds in the district above defined. Between the southern trades and this tract of ocean, there are occasional calms, often interrupted by winds, which, when the sun is in the northern hemisphere, generally blow between south-west and north-west, and during the other six months between south-east and north-east. These are sometimes called the north-west and north-east monsoons, but they are not to be classed as monsoons in the proper sense of the term. The proper monsoons occur north of this region, and consist of a north-east wind blowing from November to March, and a south-west wind from the middle of April to the end of October.

The north-east monsoon extends a little south of the line. It becomes regular near the coasts of Africa sooner than in the middle of the sea, and near the equator sooner than off the shores of Arabia. It is most regular and powerful in the month of January, especially in the northernmost angle of the Indian Ocean. It is not accompanied by rain on the Indian coast, but

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* Periodical winds, called monsoons, occur also on the coast of Mexico, blowing north-westwards along the coast from May to December, and south-eastwards from December to March. Others occur on the Brazilian coast.

blowing over a large tract of warm sea, it produces the rainy season on the eastern coast of Africa.

The south-west monsoon begins a little north of the equator, and soonest off the coast of Malabar. Its influence is felt on land along the course of the Indus. At sea it is a serene wind of moderate force, but it brings very heavy rain to the coast of Hindostan.

The change of the monsoons takes place between the latter part of March and September, and the early part of April and October; in some places a week or two earlier than in others. The change takes place gradually, and is accompanied by storms and tempests. On the wind ceasing to blow in one direction, the clouds in the upper atmosphere are at once observed to take an opposite course, but some weeks may intervene before the change is felt at the Earth's surface.

36 *Hurricanes.*—These are storm-phenomena that occur from time to time on most parts of the Earth's surface, but certain districts are remarkable for exhibiting all the phenomena of atmospheric disturbance on the grandest and most destructive scale. Under the names *Typhoon, Scirocco, Tornado,* &c. are sometimes designated storms having certain peculiarities depending on local conditions.

Hurricanes often travel far from the spot in which they originate, and their path is marked by desolation, although their consequences are often not unfavourable to health, by entirely changing and purifying the air in those districts exposed to them.

Hurricanes occur most frequently within the tropics, or rather near the verge of the tropics, and in the vicinity of continents and islands. In the northern hemisphere, the West Indian islands, and in the southern, the islands of Mauritius and Rodriguez, seem to be the foci of the most violent and destructive storms. In the former district these commence near the Leeward Islands, and travelling first W.N.W., pass out into the Atlantic round the shores of the Gulf of Mexico, and are lost between the Bermudas and Halifax. Near the Mauritius the hurricanes come from the N.E., travel S.W. by S., and return again to the east; while in the Bay of Bengal they come from the east and travel westward.

The period of hurricanes in the West Indies is from August to October, and early in June and July. In the Indian Ocean, these storms occur from December to April, and sometimes, though rarely, in November and May.

The range of these storms in the West Indies is from latitude 10° to 50° north, and longitude 50° to 100° west. In the Indian Ocean they extend over a tract of 3000 miles in length.

The motion of the air during a hurricane is by no means simple, and has induced the name of whirlwind to be given to some cases when this motion is recognised. It is produced by a mixed rotation on an axis and progression in a curved line, so that a kind of spiral results, the storm often seeming to return again a second, or even third time to the same spot, having in each of these returns a different and often contrary direction, while in places not far distant, there is not the smallest apparent disturbance of the equilibrium of the atmosphere. One of the results of this kind of motion is, that although the violence of the wind, in the active part of the hurricane, is sufficient to destroy houses, and tear up the largest trees by the roots, the rate of progress of the whole storm, from point to point, on the ocean is not greater than that of the ordinary atmospheric currents, varying, that is, from seven to fifteen miles an hour. The storm seems, therefore, to be a violent local disturbance of the equilibrium of the atmosphere conveyed along the Earth's surface, independently of, and in addition to, its own proper motion, which is round an axis.

The hurricanes of the coast of China are called typhoons, or tyfoons, and occur only, on an average, about once in three or four years, whereas not less than thirty great hurricanes have been recorded as occurring in the West Indian seas since the commencement of the present century.

There are some remarkable local storms also well worthy of notice. The *simoon* is one of these; it blows only in short gusts of unequal duration, and originates in the vast sandy plains of Northern and Central Africa. It makes its appearance during strong south-western winds, but only between the middle of June and the twenty-first of September. The gusts are burning hot, and have a putrid and sulphurous smell and suffocating feeling, occasioning profuse perspiration, difficulty of breathing, and often death, to those exposed to them.

The *harmattan* is a wind extending along the western coast of Africa, from Cape Verde to Cape Lopez, and its period of occurrence is from December to February. It blows from the side of the Great Desert, and is extraordinarily hot and dry, but not unhealthy.

These grand disurbances of the atmosphere are intimately connected with electric changes, and are often accompanied by the most magnificent exhibitions of atmospheric electricity. Important results connected with terrestrial magnetism are also found to be involved with these appearances.

37 *Relation of the Atmosphere to Water.*—It is manifest to every one in the latitudes in which we live, that the condition of the atmosphere with regard to moisture is constantly undergoing change, the air sometimes being so dry that the soil cracks and vegetation is parched, while at other times torrents of rain pour down and deluge the whole country. These conditions are, however, variable in every sense of the word, and different countries are very differently acted on by atmospheric changes.

Whatever be the sensations of dryness communicated by the air, there is always present a certain quantity of aqueous vapour, but this quantity is capable of great increase, and especially when the temperature is heightened. An atmosphere of steam is thus always mixed with the dry atmosphere of oxygen and nitrogen gas, and this steam atmosphere is sometimes suddenly and considerably increased, sometimes very rapidly diminished: sometimes it is made visible by sudden changes, while at others it continues so perfectly mixed as to be invisible to the eye. In these various stages of visibility, we speak of air as containing mist, fog, or cloud—mist and fog being conditions of the atmosphere when vapour is visible at the Earth's surface, while clouds are the visible masses of vapour of some definite form, and at a distance from the Earth.

There is a certain limit beyond which air of a given temperature will not hold aqueous vapour in perfect suspension, so that changes of temperature may cause the deposit of vapour previously held suspended and invisible, thus producing important alterations in the transparency and clearness of the atmosphere.

It is important also to consider that water in assuming a different mechanical condition—that is, in passing from the fluid state into the solid or aerial—involves very considerable electrical changes. The fluid water in its usual condition passes into the gaseous state at all temperatures; even when it is solid, this process goes on very readily; and since a large proportion of the globe is covered with water, the changes thus involved become considerable, and the equilibrium of the atmosphere is constantly undergoing disturbance from this cause alone. Perhaps, indeed, the mutual action of air and water produces many of the most marked and important atmospheric phenomena. The evaporation of water is accompanied with the apparent loss and temporary disappearance of a large quantity of heat, which is thence said to be *latent*, or concealed, and the conversion of steam into water and water into ice, reproduces or renders sensible this concealed heat.

To understand, therefore, the nature of aqueous meteors, it must be remembered that every change of condition of water involves changes to a great extent both of temperature and electricity. The most remarkable of the meteors are dew and hoar frost, mist and fog, clouds, rain, hail, and snow. With these are connected changes in atmospheric condition, made known and studied by the hygrometer, the thermometer, the barometer, and the magnetic needle. We shall here only very briefly explain the nature and cause of the phenomena themselves.

38 *Dew.*—Dew is the moisture deposited from the air, in minute globules, on the surface of various bodies, when that surface is colder than the atmosphere. This occurs chiefly at night, more especially in Spring and Autumn, but generally on clear, serene nights, when the difference of temperature between day and night produces a marked variation in the quantity of water which the air is capable of retaining in a state of perfect solution. When the vapour is made visible, the air ceases to be clear, and mists or fogs arise, but these are very different from dew both in their nature and appearance. The deposit of moisture is then only called dew when the water is precipitated on solid bodies and the air retains its transparency.

Since the formation of dew depends on the difference of temperature of the air and solid bodies with which it is in contact, and as solid bodies part with temperature with very different degrees of rapidity, it is clear that there ought to be a larger quantity of dew on those bodies which radiate heat readily than those which are slow in undergoing change; and this is indeed the case; for the polished surface of metals receives scarcely any dew, while wool, or any animal substance, or glass, radiating heat rapidly, receives large quantities. So also the interposition of any substance, such as a cloud, very sensibly affects the quantity of water deposited in this form, for it both interferes with radiation and reflects back again some heat. The dew is mainly deposited near the ground, since the radiation of heat from the Earth's surface in the evening and night produces there the greatest amount of cold. When the cold at the surface is below the freezing point, the dew freezes as it is formed, and thus are produced the beautiful appearances of *hoar frost*. The presence of a considerable quantity of vapour in the air, indicated by the deposit of large quantities of frozen dew, or hoar frost, after a clear night, has often been remarked as indicative of change of weather, and is not likely to be succeeded by steady and long-continued frost.

39 *Mists and Fogs.*—These phenomena are frequent results of a small change in the condition of the atmosphere near the ground, in those countries in which the soil is occasionally damp and comparatively warm, while the air is damp and cold. The damp air in contact with the Earth, on a calm morning, chilled by the colder air above, parts with its moisture, or, at least, the moisture assumes the form of visible vapour. Where there are vast multitudes of minute particles of carbon floating in the air, as in the neighbourhood of large cities, these mix with the vapour, and form those thick and almost opaque fogs so well known in London and other places. Thus, also, are formed thick mists in Newfoundland and on the eastern coast of North America, when the melting of icebergs, stranded on the great bank of Newfoundland, chills the air, and causes it to part with a large portion of the moisture it had before held in a transparent state.

40 *Clouds.*—Mists forming on mountains, either immediately or after being removed by drifting winds, often become true clouds, but clouds are not only formed in contact with the Earth, but often very high in the air; nor are they left in those places where they first appear. Clouds also assume an infinite variety of form, and, by decomposing or reflecting light, produce beautiful effects of colour; and they are no less remarkable for their combinations with each other, and the changes thus induced, which, as rain, hail, or snow, or electric and magnetic storms, are of very great interest in reference to the general structure and conditions of the Earth's crust: as in all cases the change of condition from visible water or steam to invisible vapour, or the converse, produces great alterations of temperature and electricity and these again react upon the rest of the atmosphere.

The clouds that are formed or float in the atmosphere, are collections of minute globules of water, preserved in equilibrium at a certain height above the Earth's surface, either because of the crossing of currents of air differently capable of retaining water, owing to differences of temperature, or because ascending currents of air prevent the further descent of vapour having a very small degree of density. During the day, the surface of the Earth generally receives a sensible addition of heat, which it parts with by radiation at night, and thus it is not unusual to see the clouds rising higher in the air as the day advances; while in the evening, after sunset, they descend and often deposit moisture.

Clouds differ so much in their appearance, their position, and their influence on weather, as to require consideration in some detail. They have been described under different names, in three groups, which appear tolerably distinct.

There is a group of clouds often seen in the upper regions of the atmosphere, and frequently in the finest weather. They are of the most delicate forms, and are known by various names to mariners and others who study the appearances of the sky. Thus mare's tail, mackerel sky, and other names, indicate their sweeping and fretted character, and they are seen also in long ranges, apparently radiating from the north magnetic pole, particularly during or after the phenomena of the Aurora, and when any great change in the magnetical condition of the atmosphere is going on.

These clouds originate from three to four miles above the sea level, and reach even to higher altitudes than this in mountain countries. They are common in the finest weather, and show the most distinct and sharpest forms when the air is driest. The technical name for such clouds is *cirrus*, or curl-clouds, and when wet weather approaches, they pass into horizontal sheets, descend lower, become denser, and lose much of their picturesque character. When seen in motion, they rarely agree in direction with that of clouds and air currents nearer the Earth.

The *cumulus*, or heaped cloud, is generally of much denser structure than the cirrus, and much nearer the Earth. Clouds of this kind convey large quantities of moisture to great distances, and act a very important part in modifying the effects of the sun's rays, often forming during the day and dispersing at night. In fine weather, they are of moderate elevation, varying from one to two miles, and they are then also of moderate extent, exhibiting well-defined roundish outlines. Before rain, they increase rapidly, sink nearer to the Earth, become fleecy and irregular, and pass into another form.

The clouds called *stratus* rest generally on the surface of the Earth or water, and thus resemble or replace mists. They are essentially night-clouds, and often pass into cumulus after sun-rise, but are greatly mixed with cumuli, forming in that case banks and ranges of cloud. It has been observed, that although these clouds and the combinations of them increase very much, and put on the most rain-like appearance, they do not actually rain so long as they retain a definite character and a separate existence.

41 *Rain.*—Rain is the deposit of moisture from clouds, in drops falling through the air; but before rain takes place, the clouds undergo a change, and pass into the state called *nimbus*. This is best seen in stormy weather, when the cumuli rise first into mountain-like masses, and afterwards change into those stratiform masses of vapour, which, occupying a middle state between cumulus and rain, are so commonly seen in changeable weather in our climate. Long ranges of delicate clouds in horizontal streaks occupy the summits, and ultimately form a crown, extending from the top in tufts, and the sudden union of such clouds immediately precedes, and is accompanied by a shower. Rain falls also occasionally, but rarely, without clouds.

When, as sometimes happens, a very large quantity of rain falls in a short period of time, it may seem difficult to comprehend exactly the physical cause, but generally the mingling together of great beds of air of unequal temperature, and in different electrical states, may be referred to as sufficient, because in the admixture of such beds of air, the united volume is not by any means capable of retaining the same quantity of water as the two separate beds had done. It is not, however, the case that admixture of air necessarily involves a fall of rain.

42 *The Distribution of Rain.*—Rain falls upon the Earth in exceedingly variable proportions; in some places the fall being periodical, in others almost

constant, and in others again, so rare as to be scarcely known, while in our country and many parts of both temperate zones, it is so variable and irregular as to induce us to assume the weather as the type of inconstancy. The quantity of rain that falls is also very different for different districts, at various seasons of the year, and in different years; depending much on local peculiarities, such as the insular or continental position of any particular spot, the mean annual temperature, the extremes of temperature, the prevailing winds, the form of the land, and its height above the sea level.

Speaking generally of that part of the habitable globe known by actual observation, we may refer to the northern and southern temperate zones as districts in any part of which rain may or does fall every day of the year, (thence called zones of constant precipitation,) and the torrid zone, where one-half of the year is characterized by extreme moisture, and the other by extreme drought. The northern zone of constant precipitation is the one of which the phenomena are best known, but many important observations have also been made in the corresponding southern zone, as well as between the tropics.

On the whole, the quantity of rain is greatest at or near the equator, and diminishes towards the poles; but too little is yet known of the mean annual rain-fall in extra-European districts, to admit of any general conclusion being drawn, or accurate comparisons made. There appears to be a much larger quantity of rain in the tropical region of the western than the eastern hemisphere, and a larger quantity in the northern than the southern zones of constant precipitation. More rain also falls on islands and coasts than in the interior of continents, on the slopes and summits of mountains than on the plains adjacent, and on the western than the eastern side of continents. In Europe, and generally in the north temperate zone, winter is the wettest season, and summer the driest; while on the east coast of Australia, the autumn and summer include the chief rain months.

Within the tropics, the rainy season follows the apparent course of the sun, and the rain is both most frequent and most abundant in the narrow zone of variable winds, already described as extending a little north of the equator, where also there are frequent thunder storms. Most of the land within this zone is the scene of almost incessant rain-fall; while in the open sea, north and south, when the trade winds are blowing, rain is extremely rare. In India, however, the monsoons greatly modify the order of the seasons, the western coast being watered by the south-east monsoon, between April and October, and the eastern by the south-west monsoon blowing from October to April. Between the coasts and in the interior of the peninsula of India, the rains are sometimes occasional through the year, and the climate partakes of that of both the east and west coast.

There are large tracts, forming a belt round the globe, in which rain is either never known to fall, or occasionally falls, but only in small quantities, and at long intervals. The most extensive of these districts includes the great Sahara, or desert of Africa, the deserts of Arabia and Persia, and that of Beloochistan. It occupies three millions of square miles. The great table land of Thibet is a similar district, occupying near two millions of square miles, and the table land of Mexico exhibits the same peculiarity over half a million of square miles. All these extensive regions are not, however, hopelessly barren, as might be expected from the absence of rain; for in many of them, the large deposit of moisture in the form of dew renders vegetation not only possible, but luxuriant.

43 *Snow.*—When moisture is precipitated from the union of atmospheric volumes of unequal humidity and temperature, it frequently happens in the temperate and frigid zones, that the temperature of the air is below the freezing point of water, and this may arise either from absolute cold or (at high altitudes) from greatly diminished atmospheric pressure. In these cases, the moisture will become frozen, and form into flakes of snow, each of which, when examined under the microscope, is found to be composed of a great number of separate and transparent crystals of ice. It is in intensely cold

weather that these are most remarkable, and many of the most interesting forms are only met with in the Polar regions. During the fall of snow, it is not unusual in temperate climates for the thermometer to rise considerably.

In all parts of the Earth, the rarefaction of the air at a certain height above the sea is sufficient to produce a temperature at which water exists in the solid form, but this limit of perpetual snow varies exceedingly with latitude and local position, rising within the tropics to upwards of 17,000 feet, and in the Polar regions descending to the sea level. The most remarkable instance of the elevation of this line occurs in the Himalayan chain, the loftiest in the globe, where the snow limit is lower by several hundred feet on the northern than on the southern side of the mountains, although from the position and the latitude, it might have been expected that the contrary would have been the case. The proportion of the absolute surface of the Earth covered with perpetual snow has not, we believe, been yet determined; and in consequence of the form of the land, and the position of the high mountains on the Earth, many of the most remarkable elevations do not reach the limit, while others, far less important, are more or less included in it. The following tabular statement will be found interesting, as giving an approximative view of the position of the snow-line in various latitudes.

Limit of Perpetual Snow.

Andes	15,000 to 20,000 feet.
Himalaya	12,000 to 16,000 „
Alps	about 8600 „
Norway	„ 5000 „
Patagonia	„ 3000 „
Iceland	„ 2000 „

Mount Erebus, in the South Polar land, rises 12,000 feet directly from the sea, covered with perpetual snow from its base to its summit.

44 *Glaciers.*—Glaciers are masses of ice, often commencing in such mountain valleys as are above the limits of perpetual snow, and reaching to considerable distances in the plains below. They have been described as icicles descending from a snow-covered roof; and as their mass and extent arise from the difference between the quantity of snow sinking into the valley in a year, and that of ice melted during the same time, they are dependent on the form of the valley, and the amount of shelter it affords, together with the mass of the snow above, and the facilities for descending the gorge, and may thus descend considerably below the snow-clad mountain tops, and advance far into retired and fertile valleys.

The most remarkable and extensive glaciers are those of the Alps, Norway, Iceland, Spitzbergen, Western Patagonia, and the shores of the Antarctic continent. The best known are those of the Alps. Except in Patagonia, the great chain of the Andes presents no glaciers, and in the Himalayan mountains there are but few, and those not extensive. The extent of glaciers in the Alps is estimated at about 14,000 square miles, and their number as 400.

45 *Hail.*—This phenomenon, which consists of the fall of frozen drops of rain, and occurs usually when the weather is warm, has often attracted attention. Connected as it is with great electrical disturbance of the atmosphere, and often with thunder storms, there can be no doubt that the main cause of the formation of lumps of ice in the air is the result of cold, produced by very sudden and rapid evaporation. The descent of hail, at least in some countries, appears limited to particular seasons and certain hours in the day; the chief hail storms having also very definite and narrow limits. Hail rarely falls on mountains in temperate climates, while in the equatorial regions it is equally rare for it to descend so low as 2000 feet. In some extreme cases, hailstones have been noticed measuring more than a foot in circumference, and weighing upwards of half a pound. These are occasionally round or polyhedral, but sometimes flat and angular, and there is great difficulty in accounting for the formation of such large masses.

The disturbance of electric equilibrium is accompanied by storms of thunder and lightning, as well as heavy rain, hail, and strong wind. These storms often take place very high in the air, having been seen in the temperate zone at a measured vertical elevation of 26,650 feet; but on the other hand, the stratum of cloud in which thunder takes place, is sometimes not more than 3000 feet above the plains.

46 *Climate, and Distribution of Heat.*—By climate, in a general sense, we understand all those states and changes of the atmosphere which sensibly affect our organs. These include temperature, moisture, variation and amount of pressure of the air, calmness of the air or the effects of prevalent winds, electricity, purity, and transparency of the air, and serenity and clearness of the sky. All such causes influence the human frame, and greatly affect the development and health of all organic beings.

Questions of temperature that affect climate must be considered on the average of a long period of time, and very different averages are obtained, according as we take the mean temperature of the whole year, of the summer months, or of the winter months. It has been found convenient to bring together the results of observation with regard to each of these points in different districts, connecting by lines the places where the same temperature obtains. In this way are formed those imaginary lines upon the Earth, known respectively as *isothermal lines* (lines of equal mean annual temperature), *isotheral lines* (those of equal mean summer heat), and *isochimenal lines* (those of equal mean winter cold). Other lines have also been determined, which assist greatly in determining, *à priori*, the climate of districts not previously known, amongst which are *isobares* (lines of equal mean height of the barometer at the sea level), but we consider only, in this place, the subject of temperature.

Owing to the position of the Earth with regard to the sun, different quantities of heat are received on different zones of the surface, varying according to latitude or distance from the equator. If the surface were uniformly level, and everywhere of the same conducting and radiating power, parallels of latitude would be at once isothermal, isotheral, and isochimenal lines, but as this is not the case, and as every unevenness of surface and every difference of material produce, both directly and indirectly, a difference in respect of temperature, it results that places, in the same latitude, rarely receive the same amount of heat in the year, and, even when they do, hardly ever have it similarly distributed. Examples of this are innumerable, and will at once present themselves to the reader's memory. The mean annual temperature of Quebec, in latitude 47° N., is nearly the same as that of Trondjem, on the coast of Norway, in latitude 63°. The temperature at Nain, on the coast of Labrador, is about 20° Fahrenheit lower than that of parts of Scotland in the same latitude, while the limit of perpetual ground-frost (32° Fahrenheit) in the northern hemisphere, rises in the Greenland sea five degrees of latitude above the Arctic circle, and on the sea of Okhotsk sinks no less than twelve degrees below it. So also the mean winter temperature of Pekin (in a latitude south of Naples,) is more than five degrees (Fahrenheit) *below* the freezing point, while that of Paris, 700 miles further north, is more than six degrees (Fahrenheit) *above* the freezing point; the mean temperature of the month of August in Hungary is nearly 70° Fahrenheit, while in Dublin, situated on the same isothermal, it is barely 61°. The winter temperature of Dublin, however, is more than $3\frac{1}{2}$° higher than that of Lombardy, although its mean annual temperature is more than $4\frac{1}{2}$° lower than that of the towns in the latter country. Thus, it is clear that the same mean annual temperature may be distributed in a variety of ways, in the different seasons of the year, while, owing to local influences, places on which the sun shines for the same number of hours during the year, may receive very different amounts of heat. It is found that, in the northern hemisphere, there are two poles of cold, round which the curves are grouped; the Western, or American pole, being in 80° N. lat., and 260° E. long., with a temperature of $3\frac{1}{2}$° below zero of

Fahrenheit, (35½° below the freezing point of water,) while the eastern, or Siberian pole is in the same latitude, but in 95° E. long., with a temperature of one degree of Fahrenheit, being thus five and a half degrees warmer than the other. The isothermal lines round these two poles, and their inosculation have not been accurately determined.

On the whole, the following table seems to give the most useful general idea of the distribution of heat on the globe; the different regions in the two hemispheres being distributed into zones according to their mean annual temperature:—

Designation.	Limits.	Mean Annual Temperature.
Hot or equatorial zone .	Between isothermal curves 77° both hemispheres	+ 79°·70 Fah.
Warm zone	" " 77° and 59°	+ 68°·00
Mild zone	" " 59° and 41°	+ 50°·00
Cool zone	" " 41° and 32°	+ 36°·50
Cold zone	" " 32° and 5°	+ 18°·50
Frigid or polar zone .	Within isothermal curve of 5°	+ 3°·20

It has been attempted to determine also the mean temperature of large portions of land. Thus, the temperature of the tropics generally, near the coast, is estimated at 81½° Fahrenheit, but in the interior is much higher. The mean temperature of the whole Earth has been recently estimated by Dove to amount to 58·2° Fahrenheit, being about 54° in the month of January, and 62° in July. Many interesting conclusions are obtained from the study of this branch of Meteorology.

As among the remarkable results shown by the recently published maps of Professor Dove, we may also here mention that the mean temperature of the northern hemisphere is nearly 60°, and that of the southern only 56°; that the mean winter temperature in the former is, however, less than 49°, and in the latter 53½°, while the summer temperature in the northern hemisphere is 71°, and in the southern only 59½°; the limits of deviation in the one case being 12°, and in the other only 6°. These tables are deduced from observations extending over a series of years at as many as 900 stations.

The changes of temperature above referred to are assumed and described throughout, if possible, for the level of the sea; but as we have already seen that on the higher slopes and summits of many mountain districts, in various parts of the world, snow not only falls, but there is a limiting plane above which it never melts, it is clear that there must also be gradual changes of temperature on the sides of mountains, and at all considerable altitudes. This is, indeed, the case; and elevation even to a very moderate extent often produces considerable modifications of climate.

It is a general rule, that the actual temperature of any part of the Earth's surface depends, partly on the mean annual temperature at the sea level, as determined by the isothermal line passing through it, and partly on the elevation above the sea, or the greater or less column of air that the solar rays pass through, the temperature diminishing one degree for about three hundred feet of vertical elevation. Many important local exceptions prevent this from being a calculation to be depended on, in any spot not yet determined by actual measurements; but, as a general rule, it is applicable between the tropics. Thus, many cities situated on elevated plains are cooler than would appear from the isothermal line passing through them, and thus also on the slopes of mountain chains, within the tropics, we find all varieties of climate, sometimes within two days' journey.

The winds which blow over a country pass sometimes over very large areas of warm sea, sometimes over cold seas, and sometimes over ice, while, in some cases, also, they have just proceeded over extensive ranges of land, either heated by the sun's rays, or chilled by the presence of perpetual snow. It is therefore evident that the climate will be very much modified by the nature of the winds that blow, inasmuch as these not only affect the temperature, but also very greatly influence, and even bring with them, the amount and regulate the distribution of moisture. The observations already offered on the subject of winds and rain, together with those which will be given when considering the phenomena of the ocean, have reference to climate, and the general conditions which render a country fertile or habitable.

It is commonly known and felt that both cold and heat are more intense when the sky is clear than when it is overcast with clouds, and thus it arises that those countries where the winds bring large quantities of moisture, and are met by others differently constituted in this respect, and where, consequently, clouds and mists are frequent, the climate will be essentially different from that of countries in which the same mean annual temperature is accompanied by a clear sky. England and Holland are examples of this difference.

47 *Conclusion.*—The meteorological portion of Physical Geography, which we are now bringing to a conclusion, shows that the various processes going on in the vast aerial ocean, are so intimately connected, that each separate meteorological process is at the same time modified by all the rest. This complication of causes and effects renders it very difficult to interpret fully and clearly the different phenomena, and almost prevents any such prediction of atmospheric changes as is required or demanded for agriculture and navigation, or even for the conveniencies of life. Those, therefore, who look only to an immediate result and power of prediction, may believe that this branch of science has made but little progress. But the results of science are not always in this way immediately and positively applicable, and although many facts and laws of extreme practical interest have been made known already in the pursuit of meteorology, the main value of the science must still be placed in the knowledge of the phenomena themselves, and the extent and truth of those partial generalizations which have been suggested, and which have yet to be examined and verified.

Among these general results it appears that considerable deviations from the mean distribution of temperature are rarely local in their occurrence, but extend uniformly over large areas, reaching their maximum at some determinate place, receding gradually until its limits are reached, and then when these are passed, extending into great deviations in the opposite direction. It appears, too, that similar relations of weather extend more often from south to north than from east to west, but there is no reason for supposing that a severe winter will be followed by a hot summer, or a mild winter by a cool summer.

With regard to instruments, it is important to remember that the barometer indicates to us what takes place in upper and distant regions of the atmosphere, while the thermometer and hygrometer give purely local results; but as important changes of weather do not usually arise merely from local causes situated at the place of observation—their origin occurring rather in disturbances of the equilibrium of the currents of the atmosphere and electrical changes begun afar off—various and long-continued observations, and a careful comparison of results, are absolutely required for accuracy in meteorology.[*]

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[*] The recent introduction of the *aneroid barometer*, an instrument for measuring the pressure of air by means of a partial vacuum—avoiding the column of fluid hitherto employed—is worthy of some notice in this place.

At the present time, and judging from the instruments hitherto made, there seems no probability of the ordinary mercurial barometer being superseded, but the application of the aneroid principle to improved machinery promises to be ultimately very important, on account of the convenience of form and facility and safety of transport. For these reasons, the aneroid may be carried by the traveller to measure the height of mountains, and obtain much other useful and desirable information, which the inconvenient form and fragile nature of either the common or mountain barometer render difficult to procure.

CHAPTER IV.

ON THE FORM AND DISTRIBUTION OF THE LAND.

§ 48. What is meant by 'land.'—49. Distribution of land.—50. Continents.—51. Islands.—52. Inequalities of the surface of land.—53. Low plains and steppes.—54. Deserts.—55. Silvas.—56. Llanos.—57. Pampas.—58. Savannahs, or prairies.—59. High plains, table lands, or plateaux of the Old World.—60. Table lands of America.—61. Mountain systems of the earth.—62. General connexion of the mountains of the Old World.—63. Mountain chains of the New World.—64. Mountains of Australia.

WHAT is meant by Land.—Under the term *land*, is included every variety of mineral substance and rock formation usually existing in a solid form upon the Earth, and not covered constantly by water; and it is matter of familiar knowledge that the surface of the Earth thus presented, is exceedingly irregular in outline and elevation, being collected into some extensive continental masses, and a vast multitude of smaller areas, called islands. The form and position of the continents—their extent both in magnitude and direction—the position of the several portions of their surface with respect to the sea-level—the nature, extent, and direction of their elevations above, and depressions below, this general level—together with the position, the mode of grouping, and the irregularities of surface of the different insular areas—these are all points of interest with respect to the land, and together they involve a description of the physical peculiarities of this portion of our globe.

49 *Distribution of Land.*—The land is very unequally distributed in the two hemispheres separated by the Earth's equator; the proportion of land to water on the northern side being very much larger than on the southern; so also the absolute quantity of dry land on the eastern side of the Atlantic is much larger than on the western; and if an observer were stationed vertically above a point in England, not far from the Land's End, in Cornwall, and could thence see one half the globe, he would have before him almost all the land; while, on the other side, would be scarcely anything but a few islands and a portion of Australia and Patagonia visible above the water.

Many facts have been noted in reference to this subject. The whole area of land on the Earth has been estimated at about 51½ millions of square British statute miles, and of this quantity more than three-fourths lie to the north of the equator. Only about one twenty-fourth of the whole area of land consists of islands (Australia being excluded). If we compare the north with the south temperate zone, we find the proportion of land nearly as thirteen to one; while, on the equator, about five-sixths of the circumference is water. It appears also that only one twenty-seventh of the existing land has land directly opposed to it in the opposite hemisphere.

50 *Continental Land.*—Of the whole area of land, that portion which, being connected together and continuous, is called *continent*, consists of two principal portions, one on the eastern side, containing Europe, Asia, and Africa, sometimes called the Old World, or the great continent; and the other the western, including the two Americas, and known under the name of the New World.

The principal direction of the old continent is from east to west, or, more precisely, from north-east to south-west; while the western continent extends from north-north-west to south-south-east. Both continents are terminated towards the north at about the seventieth parallel of latitude, and both run into pyramidal points towards the south, having submarine prolongations indicated in South America by islands, and in South Africa by shoals. The area of the greater (the old) continent, together with its adjacent islands, is about thirty-three millions of square miles; that of America, only fourteen millions and a half; and Australia, with the Polynesian Archipelago, barely four. Of the portions of the old continent, sometimes called separately continents, Asia forms one-half, Africa three-eighths, and Europe only about one-eighth of the whole.

The pyramidal termination, southwards, of all the principal land on the globe, is a very remarkable fact; and it has been observed, that the southern extremities of Africa, Australia, New Zealand, and South America, form a regular gradation, each reaching nearer the South Pole, in the order here expressed, and the projecting points are as nearly as possible in the same meridian in the two hemispheres. Pyramidal terminations obtain also in the peninsulas of Arabia, Hindostan, Malacca, and California, and in the chief masses of land in the Mediterranean, as Italy and Greece.

The form and indentation of the coast lines are phenomena of considerable interest, especially as they bear on commercial enterprise; and the existence of those peninsulas and irregular projecting tongues of land, or detached islands, which abound chiefly on the coasts of Europe, Eastern Asia, and Eastern North America, is worthy of notice, in reference to the progress of the civilization of mankind. All the shores of Europe are deeply indented by bays, and there are also a number of inland seas of very considerable magnitude, so that our continent has a greater proportion of maritime coast than any other district of the same magnitude. The European coast line measures, indeed, nearly twenty thousand miles. The coast of Asia also exhibits large seas, bays, and gulfs, which are sheltered by a chain of islands, rendering navigation dangerous. The whole length of Asiatic coast amounts to about thirty-three thousand miles. The coast of Africa measures nearly fifteen thousand miles in length, and is little indented except along the coast of Guinea and in the Mediterranean. The American coast is very different in different parts, and its whole length is upwards of forty thousand miles. The shores of the Icy Ocean are very complicated, and other parts of the eastern coast, as far as Mexico, exhibit a considerable number of gulfs and inlets, but the shores of South America are very entire, except at the southern extremity. On the whole, the result of investigation on this subject shows that the western coast of the Old World, in Europe, is the most deeply and frequently indented, and the best adapted of any on the globe to the wandering habits of mankind.

51 *Islands.*—The islands, or portions of land separated by water from the great continental areas, vary in character very greatly, some being arranged in distinct groups and series, having common peculiarities, others being related rather to the adjacent mainland. These may be considered to form two principal sets—viz., the elongated or continental islands, generally belonging to the nearest considerable mass of land, and the round or pelagic islands, forming systems, generally occurring in the open ocean, and apart from continental lands. The former are generally in series, and appear in some places to give indication of extensive submerged continental lands, as in the long suite of islands which, beginning to the south of New Zealand, sweeps round the east and north sides of New Holland, including New Caledonia, the New Hebrides, the Solomon Islands, New Zealand, New Guinea, &c., and the yet more remarkable islands beginning with the Philippines, extending northwards through Formosa, the Loo-Choo and Japanese Islands, and so to the Kurile Islands. The chain of islands of which the Moluccas, Java, and Sumatra form the principal in point of magnitude, the important island of Madagascar, off the coast of Africa, the main chain of West Indian Islands, in the Gulf of Mexico, and the long ranges of islands on the northern coast of North America, are further examples in distant countries; while in Europe, the chains of islands on the coast of Scandinavia, the British islands, the elliptic islands between Italy and Spain, the islands

on the east coast of the Adriatic, and the islands of the Greek Archipelago, complete the series of this class of insular land.

The principal islands belonging to the second or oceanic group are, the Friendly, the Society, the Marquesas, the Sandwich, and other groups in the South Pacific; the Canary Islands, the detached islands in the Indian Ocean, the Galapagos, and, generally, the multitudinous group of single volcanic islands in various parts of the world; and also the groups of coral islands. These form two groups, distinguished by their origin, and generally not less distinct by their vertical elevation.

Perhaps, the general plan and nature of these different kinds of islands will be best understood if we consider them as due in the first case (continental islands) to the slow elevation or depression of large masses of land on a linear axis, by the tilting up of one edge of a plane. The other two cases are also understood, if we consider the one as resulting from the local elevation of certain small areas on a point of upheaval, and the other as the consequence of slow depression of areas of broken land without much tilting, and while circumstances were favourable for the rapid increase of growth of marine animals.

The facts connected with the actual horizontal configuration of the land are perhaps more important in Physical Geography than has often been thought, and the evidences derived from the observations on island distribution are not the least remarkable. The lines already alluded to, one extending from New Ireland to the New Hebrides, and the other to the Sandwich Islands, each range north-west, with perfect parallelism, for 2000 miles, at a distance of 3500 miles apart, and indeed this same direction (north-west) obtains to a greater or less extent through the world, not only in islands, but in those higher elevations above the mean level which come under the denomination of mountain chains. The phenomena connected with these we shall describe presently.

52 *Inequalities of the Surface of Land.*—Not only is it the case that the land, whether continental or insular, offers various peculiarities of horizontal configuration, but each mass of land also presents some distinct features of inequality of level. Occasionally, but very rarely, large tracts may be observed extending in every direction, at nearly the same level, and removed but little above the surrounding water. Much more frequently there occur undulations in every extensive area, and also different degrees of absolute elevation above a mean level. Such varieties produce the phenomena which are described under the names of *plains* or *table lands*, and these are rent asunder by valleys and gorges, or pierced through by mountain chains, and broken into picturesque forms of hill and dale.

These general inequalities of surface are exhibited in their most typical and characteristic form in those districts where their details can be studied, and their origin therefore be made the subject of speculation; but they are often mingled together with more or less of indistinctness, and thus their true characters become concealed or lost. It is only in large tracts of land that they are seen in all their grandeur: in islands and small parts of continents, where more than one prevails, the great force of the phenomenon is not appreciated.

There is much mutual relation amongst these varieties of vertical profile, and also much reference in all of them to the structural peculiarities of the Earth's surface. Thus, they require careful consideration, and the different facts that have been recorded concerning them, possess direct interest, not only as affording examples of the physical outline of our globe, but also in their bearing on those conditions which affect man as its chief inhabitant.

53 *Low Plains and Steppes in Europe and Western Asia.*—A very large quantity of the land is distributed as low plains near the sea level, and often not far from a coast line. These occasionally present hills of moderate altitude, in most cases not reducible to any general system. Sometimes these hills are long waves or undulations, and often perfectly uniform in structure

for many miles. Under the name of *plains*, are designated the low flat lands of Northern Germany and Russia, and of Lombardy; the flats of Tartary are called *steppes;* those occupying the central parts of Northern Africa are *deserts;* those in the northern part of Southern America, *silvas*, or forest deserts; those of other parts of South America, *llanos* and *pampas;* and those of North America, *prairies*, or *savannahs*. Many are the peculiarities of these districts, but they have in common the important physical feature of wide extent, uniform general level, and small elevation above the sea.

These tracts of flat land may be considered as including several distinct areas. In the northern part of the Old World they are traceable from the shores of the German Ocean, through Holland and North Prussia into Russia, thence into Siberia, and so at intervals, only broken by low elevations, to the coast of the Pacific in Behring's Straits. Within these limits, they occupy an area of not less than four and a half millions of square miles, and while on the one side Holland would be overflowed by the sea if it were not for its dykes, so on the other, near Astrakan, the plains sink still lower, and the country around the Caspian Sea and the Sea of Aral, forms a vast cavity of 160,000 square miles, all considerably below the bed of the ocean: the surface of the Caspian Sea itself, at the lowest point, being depressed 348 feet.

Towards the eastern extremity of Europe, the great plains assume the peculiar character of a desert, consisting of level wastes destitute of trees. These *steppes* begin at the river Dnieper, and extend along the shores of the Black Sea, including all the country north and east of the Caspian and Independent Tartary, and passing between the Altai and Ural mountains, occupying all the low lands of Siberia. Hundreds of leagues may be traversed eastwards from the Dnieper without variation of scene, and a dead level of thin but luxuriant pasture, bounded only by the horizon, fatigues the eye of the traveller day after day by the same unbroken monotony. So long as the vegetation remains, horses and cattle beyond number give animation to the scene, but winter comes on in October, and the whole area then becomes a trackless field of spotless snow. Fearful storms rage, and the dry snow is driven by the gale with a violence which neither man nor animal can resist, while the sky remains clear, and the sun shines cold and bright above. The summer's sun is as severe in its consequences in these wild regions as the winter's cold. In June, the steppes are parched, no shower falls, nor does a drop of dew refresh the thirsty earth; the sun rises and sets like a globe of fire, and during the day is obscured by a thick mist. Thus, in some seasons, the drought is excessive, and the air is then filled with dust and impalpable powder, the springs become dry, and the cattle perish in thousands. Death triumphs over animal and vegetable nature, and desolation tracks the scene to the utmost verge of the horizon.

Of the whole extent of these plains, a very wide range is hopelessly barren; the country from the Caucasus, along the shores of the Black and Caspian Seas (a dead flat, twice the size of the British islands) being desert, and destitute of fresh water, while between the Caspian Sea and the Lake of Aral, there is, for the most part, an ocean of shifting sands, often driven by appalling whirlwinds.

The Siberian or Asiatic portion of the great northern tract of low land in the Old World, occupies more than seven millions of square miles, and is rarely visited except along its outer boundary. Parts of the tract are occupied by a rich black mould, covered with grass and trees, but other and larger portions are hopelessly and desolately barren.

To the lowlands belong almost the whole of Northern Asia to the northwest of the volcanic chain of the Thian-schan; the steppes to the north of the Altai and of the Sayan chain; the countries which extend from the mountains of Bolor, or Bulyt-Tagh, ('cloud mountains,' in the Uigurian dialect,) which follow a north and south direction, and from the Upper Oxus, whose sources were found by the Buddhistic pilgrims, Hiuen-thsang and Song-yun, in 518 and 629, by Marco Polo in 1277, and by Lieutenant Wood in 1838;

in the Pamer Lake, Sir-i-kol, (Lake Victoria,) towards the Caspian; and from Tenghir, or the Balkhasch Lake, through the Kirghis Steppe, towards the Sea of Aral and the southern extremity of the Ural mountains. As compared with high plains of 6000 to 10,000 feet above the level of the sea, it may well be permitted to use the expression of 'lowlands,' for flats of little more than 200 to 1200 feet of elevation. If the word plateau, so often misemployed in modern works on geography, is to have its use extended to elevations which hardly present any sensible difference in climate and vegetation, the indefiniteness of the only relatively significant denominations of highlands and lowlands, will deprive physical geography of the means of expressing the idea of the connexion between elevation and climate, between the profile or relief of the ground and the decrease of temperature. Humboldt, to whom we are indebted for the above information on this subject, remarks, 'When I found myself in Chinese Dzungarei, between the boundary of Siberia and Lake Dsaisang, at an equal distance from the Icy Sea and from the mouth of the Ganges, I might well consider myself in Central Asia. The barometer, however, soon taught me that the plains through which the Upper Irtysch flows are hardly more than from 800 to 1200 feet above the sea. Further to the east, the Lake Baikal is 1420 feet above the sea.'*

The low lands on the south-side of the great back-bone of mountains, running east and west through the Old World, are of very different kinds, in some respects, from those already described. They exhibit a more tropical character, and are strikingly contrasted in their different parts,—either rich in all the exuberance that heat, moisture, and soil can produce; or covered by wastes of barren and burning sands:—some of them being in the most advanced state of cultivation, and others in the wildest garb of nature.

The Great Desert of Northern Africa forms, perhaps, the most striking example of one of these conditions. The alluvial plains of China contrast this perfectly, and are paralleled in some respects by the vast and rich low tracts near the mouth and lower valley of the Ganges and Brahmapootra, and the plains of Hindostan. The latter are rich and highly cultivated, offering little that is extraordinary beyond the fact of their wide extent. The former, or desert lands, require more detailed notice.

54 The Sahara, or great African Desert, occupies the central part of Northern Africa, reaching from the rocky country confining the Nile valley to the very shores of the Atlantic. Its length is upwards of 2500 miles, and its greatest breadth 1200 miles. Its area has been stated to amount to two and a half millions of square miles, and it runs out into the Atlantic, being continued by extensive sand-banks far beyond the coast.

For the most part, the tract is level and low, but is broken occasionally by stony ridges, more than one of which crosses it in 15° E. long., and by the presence of a little clay these admit of vegetation. The desert is thus divided into an eastern and western part—the eastern, or Lybian Desert, being the smaller, and the most favoured. For the most part, its surface is not covered with sand, but formed of hard horizontally bedded sandstone rock, perfectly smooth and level. At intervals, small spots occur watered by springs and enlivened by the presence of vegetation. These are generally depressions below the surface, and are called *Oases*. The largest is nearly a hundred miles long, and from one to fifteen miles wide, but the others are much smaller.

The western portion of the Sahara contains some narrow tracts along its northern border, adapted to cultivation, but the rest of the district is almost entirely unfit for any kind of agricultural or horticultural employment. The soil is sometimes of fine sand, on which low ridges appear like the waves of an agitated sea, but in other places it is much harder, and more gravelly—though still perfectly and hopelessly barren. In several spots, beds of salt

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* Humboldt's *Aspects of Nature*, vol. i. p. 76.

occur, three of which are known and have been described, and there are also brine springs, and thick incrustations of salt on the ground, produced by evaporation.

On these interminable sands and rocks no animal—not even an insect—breaks the dread silence, nor is a tree or a shrub to be distinguished during days of incessant travel. In the glare of noon, the air quivers with the heat reflected from the red sand, and the night is chilly, under the clear sky sparkling with its host of stars. In these plains the traveller is frequently deceived by the deceptive appearance of water produced by mirage.

55 *Silvas of the Amazons.*—The plains of America differ distinctly from those of the Old World, and are known under various names, each referring to some physical peculiarity. Commencing with the northern or tropical part of South America, we find there a range of low land covered with forest, (thence called *Silvas,*) occupying more than a million of square miles, and drained by the most gigantic river on the Earth, the Amazons. This tract is so subject to inundations, that probably not less than 200,000 square miles are annually laid under water, but the whole is covered with exceedingly thick wood, rendered perfectly impenetrable by brushwood and innumerable creepers. The amount of rain falling during the year, the intense heat of a tropical climate, and an inconceivably rich soil, here produce an exuberance of vegetable and animal life, which actually offers a bar to civilization, not less effectual than the gloomy sterility of the African deserts. The native Indians seem irredeemable, and sunk in the most wretched barbarism, and there appears no prospect whatever of any improvement in the district, since man can find no spot on which to commence his operations.

56 *Llanos.*—These are tropical plains, situated chiefly on the left bank of the river Orinoco, and they are continuations northwards of the forest plains of the Amazons. Their area amounts to near 350,000 square miles, or about twice the extent of France, and although a small portion forming the delta of the Orinoco is wooded, the remainder of the whole region is entirely destitute of trees.

One portion of these plains, the Llanos Altos, rise gradually from the banks of the river, but so gently that the rise is imperceptible to the eye, amounting only to an elevation of five hundred feet in a distance of more than one hundred miles. At this point flat low banks arise, elevated only five or six feet, but extending at a dead level for about thirty or forty miles, and forming a water shed. On the other side, the plains descend towards the Caribbean Sea, somewhat more rapidly than to the south, but still imperceptibly. The summit forms a very low table-land, consisting of sand mixed with calcareous rock, and is barren, with the exception of a few hardy grasses, the rain that falls not forming into pools and fertilizing the land, but sinking into the sand to some beds of impermeable argillaceous rocks, and then running off in springs or rivulets to the plains below.

The larger and more level portion of the Llanos lies along the base of the rocky elevations, which commence the chain of the Andes, and extend from 9° N. lat. to the equator. These, though further from the ocean, are much lower than the Llanos Altos, the lowest portions being only two hundred and twenty-four feet above the sea, (from which they are distant five hundred miles,) and rising to the south and west to the height of five hundred feet. These plains are so nearly level, that the currents of two rivers in their lower course are imperceptible, and the waters flow back towards the sources, when the wind blows strongly in that direction, or when the Orinoco, to which they are tributaries, becomes swollen. In these plains, no rock, no stone, not even a pebble is seen; there are no inequalities, except some low hills of sand, rising a few yards above the common level, and some slightly elevated grounds, having an area of one hundred square miles or more, which can only be discovered by a practised eye, and whose surface is completely flat. The soil is a mixture of sand and calcareous rock, with some mould. Grass grows everywhere, but there are no trees, or even bushes, except a few isolated palm-trees, at great distances from each other, and some bushes on the banks of the rivers.

57 *Pampas.*—The Pampas are treeless plains, which extend from 22° S. lat. to the most southern limits of the American continent, occupying a total length of two thousand miles. The breadth, throughout this vast distance, is very various, rarely however less than two hundred and forty miles, and between latitudes 26° and 38° amounting to nearly double that. The area, estimated roughly, is about 750,000 square miles, or nearly four times the whole extent of France.

There is necessarily great difference in climate, and also in the nature of the surface and the vegetable productions, in plains extending thus through thirty degrees of latitude, (one-sixth of the half great circle from pole to pole.) The southern portion is called the Pampas of Patagonia, and present the appearance of a number of step-like terraces, running north and south, each slightly rising to the south, generally very sterile, but occasionally clad with verdure. The surface is diversified by huge boulders, tufts of brown grass, low bushes armed with spines, brine lakes, white snowlike incrustations of salt, and black lava platforms like plains of iron. The plains are, here and there, intersected by a ravine or a stream, but the waters do not fertilize the soil. The transition from heat to cold is rapid and extreme, and piercing winds rush in hurricanes across the district. Towards the north, the Pampas of Buenos Ayres are separated from those of Patagonia by several ridges of table-land, and present an extensive surface of ground, not without irregularities, though these are too slight to be denominated hills. A large portion of the southern part of this district is occupied by swamps and fens abounding in lagoons and wide-spreading salines; one of the swamps or lagoons alone (that of Ybera) occupying one thousand square miles, and being entirely covered by aquatic plants. These swamps are greatly swollen by the annual floods of the rivers, which inundate the Pampas, destroying vast numbers of cattle, but leaving behind thick beds of fertilizing mud.

Beyond the river Salado, the face of the country changes, the swamps ceasing, and being succeeded by very slightly undulating and dry plains, covered with luxuriant grass, and occasionally by thistles eight or ten feet high, used as fuel. Further to the west, there occurs an extensive pastoral, and also an agricultural district, separated by a line drawn on the meridian of 66° W. long., the pastoral district being to the east. The surface of the latter is almost everywhere a dead level, but large shallow salt lakes occur in very small depressions, one of them being fifty miles long and twenty miles wide. The soil is good, consisting of a dark friable mould, without a pebble: no trees occur, and there are no permanent water-courses. The district affords admirable feeding ground for horses and cattle, which were introduced by the Spaniards, and have replaced the llamas, the indigenous ruminating quadrupeds of the country. It is calculated, that there are a million of horned cattle, and three millions of horses fed on these plains.

The western or agricultural district is less level than the pastoral; the soil, consisting of loose sand impregnated with saline matter, being entirely unfitted for the growth of grass, although when irrigated it is exceedingly fertile, and particularly adapted for the growth of fruit-trees. This tract is succeeded to the north by a salt desert, consisting of a wide plain, extending about 200 miles from east to west, and 140 miles northward, which is level and smooth as a floor, and snow-white with superficial salt, stretching its treeless and shrubless wastes on all sides to the horizon, unbroken by any object save a few stunted, straggling, and leafless bushes. Throughout the whole district no grass grows, and there is a great scarcity of water. Rain has been known not to fall for eighteen months, and dews are entirely unknown.

58 *Savannahs, or Prairies.*—The prairies, or, as they are sometimes called, savannahs, are vast tracts of plain country of inconsiderable elevation,

occupying the central part of North America, estimated by Humboldt to amount to nearly two and a half millions of square miles, and extremely varied in climate, in character, and in productions. They have been divided into three classes—1. The heathy or bushy; 2. The dry or rolling, generally destitute of all vegetation but grass, and by far the most common and extensive; and 3. The alluvial or wet prairie, abounding in pools, and the frequent resort of the wapiti and other deer, and of wild horses.

The vast savannahs on the banks of the Mississippi are covered with long grass; and in the southern districts, as well as on the banks of streams, are occasionally clothed with trees, but these are rare exceptions to the general monotony. A salt efflorescence is often exhibited on their surface, and they frequently possess a deep rich soil.

Many of the plains of North America are covered by forest vegetation, but this has been greatly cleared in the United States, as the white man has advanced. The forests are not throughout of the same character; sometimes consisting of a rich variety of magnificent trees, while over many hundreds of square miles there extend vast monotonous tracts of sand, clothed only with gigantic pines, and characteristically denominated pine-barrens.

59 *High Plains, Table-Lands, or Plateaux of the Old World.*—A very considerable portion of the dry land upon the globe consists of land extending for great distance at a considerable elevation above the sea. Such land often presents a greatly varied surface, and is generally connected with important mountain chains. An example of such table-land in Europe is seen in the central plateau of Spain, consisting of a tract of nearly 100,000 square miles, elevated from 2000 to 3000 feet above the sea, and nearly surrounded by mountains. Other plateaux of enormously greater dimensions, occur in other parts of the world.

This table-land of Spain is varied by mountain ridges, (*sierras*,) some of them of considerable height. There is a want of cultivation in many parts, owing to the small quantity of rain that falls; and the whole area may be described as monotonous and naked, although corn and wine are produced in abundance in some places, while others serve for pasture. This table-land is more fertile on the Portuguese side.

The high land of Spain is continued, though at a much lower elevation, through the South of France, but chiefly by hill and low mountain ranges. The table form being rather characteristic of the eastern than the western portion of the great continent, first begins to exhibit the peculiar and striking features of such tracts in the Balkan range of mountains, which rises very abruptly from the shores of the Adriatic, and is everywhere rent by deep and tremendous fissures, transverse to the principal direction of the high land.

From this point an elevated plateau is continued, with few intervals, across Asia, as far as the Pacific Ocean; its breadth gradually expanding till it amounts to 2000 miles. It is interrupted in some places by lofty mountain chains, and its altitude varies greatly, but is throughout considerable.

The western portion of this vast tract forms the table-land of Persia, and extends from the shores of Asia Minor, nearly to the right bank of the Indus. It occupies an area of 1,700,000 square miles, and is generally 4000 feet above the sea, but in some places rises to 7000 feet. The eastern portion is very much larger, (amounting to 7,600,000 square miles,) and in some places attains an elevation of 17,000 feet.

It must not be understood that these high lands present generally an absolute level, or resemble in this respect the steppes, deserts, or savannahs, already described. They are often bounded by mountain ranges, and the highest mountains of the world rise out of them. They occasionally also exhibit in their wide extent many mountain features.

Among the westernmost portions of the great Asiatic table-land may be observed the cold, treeless plains of Armenia, 7000 feet above the sea, and the great salt desert, and adjacent sandy deserts of Irak and Kerman, in

Persia. Throughout this wide area, there is scarce any cultivation, the brick-red sand being drifted about by the wind into wave-like hills, or the soil being covered with a thick efflorescence of common salt and nitre.

The oriental plateau of Thibet is separated from that of Persia by a spur of the Himalayans, and from the plains of Hindostan by the main chain of the Himalayans, rising in some places to the height of 28,000 feet. The Altai mountains separate the district from Asiatic Siberia, while on the east they are closed in by the almost unknown mountain chains of western China. The height of this vast plateau above the sea varies from about 4000 feet in the northern portion to as much as 15,000, or even in some places 17,000 feet near the Himalayans, and the district is traversed by three mountain ranges.

A plateau of considerable, but very unequal elevation, having the names of Gobi, Scha-mo, (sand desert,) Scha-ho, (sand river,) and Hanhai, runs in a S.S.W., N.N.E. direction, with little interruption, from Eastern Thibet towards the mountain knot of Kentei, to the south of Lake Baikal. This swelling of the ground is probably anterior to the elevation of the mountain chains by which it is intersected; it is situated, as already remarked, between 79° and 116° longitude from Paris, 81° and 118° east from Greenwich. Measured at right angles to its longitudinal axis, its breadth is, in the south, between Ladak, Gertop, and H'lassa, the seat of the great Lama, 720 geographical miles; between Hami, in the Celestial Mountains, and the great bend of the Hoang-ho, near the In-schan chain, hardly 480; and in the north, between the Khanggai, where the great city of Karakhorum once stood, and the chain of Khin-gan-Petscha, which runs north and south in the part of the Gobi traversed in travelling from Kiachta, by Urga, to Pekin, 760 geographical miles. The whole extent of this swelling ground, which must be carefully distinguished from the far more elevated mountain range to the east, may be approximately estimated, taking its inflexions into account, at about three times the area of France.

No portion of the so-called Desert of Gobi (parts of which contain fine pastures,) has been so thoroughly explored in respect to differences of elevation, as the zone of nearly 600 geographical miles in breadth, between the sources of the Selenga and the Great Wall of China, and it has been determined that the mean height does not amount to more than about 4000 feet, instead of double that elevation, as was at one time supposed. It appears also that Thibet is not at all an unbroken plain, or table-land, but a district intersected by mountain groups, belonging to distinct systems of elevation, and containing but few plains, while the loftiest of them are not more than 13,340 feet above the sea level, and the mean elevation of the plateau is not more than 11,510 feet.*

Table-land is not unfrequently characteristic of islands as well as continents, and on the coast of Europe the Faro Islands, situated due west from Norway, exhibit this feature, rising at once 2000 feet, and presenting nearly the same elevation over a great part of the group. The north-western part of Scotland and the central portion of Ireland also, partake of similar character, but the elevation is not so considerable.

Africa exhibits moderately elevated table-land, over the whole, or nearly the whole of its southern portion, but the greater part of that continent is as yet unexplored by white men. North of the Cape of Good Hope, the land rises to about 6000 feet, and the continent has recently been crossed by Dr. Smith, on the tropic of Capricorn, and by some native travelling merchants about 12½° further north. At the Cape, the breadth is about 700 miles, and in the last-mentioned latitude about 1600 miles, and within these limits the table-land appears unbroken by any lofty range of mountains, although frequently rent by precipitous, deep ravines.

The southern portion of Africa is somewhat better known, and presents

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* *Aspects of Nature*, ante cit., vol. i. p. 79.

some lofty plains, projecting into the lower flat ground, like promontories. One of these terminates with the Table Mountain, at the Cape of Good Hope.

60 *Table-Lands of America.*—The table-lands and plateaux in the New World are not so extensive as in the old, but a wide and lofty tract occupies the greater part of Mexico, extending also to California. It begins at the Isthmus of Tehuantepec and reaches northwards for 1600 miles, expanding towards the north to a breadth of about 360 miles. The most easterly part of this plain is 7500 feet above the sea, and it rises towards the west till it becomes 9000 feet high in Mexico, whence it diminishes gradually to 4000 feet. In California it is about 6000 feet above the sea. It is throughout torn by narrow, deep cavities, and the descent to the low lands is on all sides (but especially the east,) exceedingly precipitous.

South America is not without table-lands of some importance, though more remarkable for great altitude than extent. One of the most extraordinary, that of Desaguardero, has an absolute altitude of 13,000 feet. Its breadth varies from 30 to 60 miles, and it stretches 500 miles along the top of the Andes. The whole area includes 150,000 square miles, and presents a considerable variety of surface. The city of Potosi stands on this plain, at an elevation of 13,350 feet, and lofty mountains rise on each side of it.

The table-land of Quito is another remarkable instance of extensive high ground. It is 200 miles long and 30 miles wide, at an elevation of 10,000 feet and is bounded by a range of the grandest volcanoes in the world. Mexico also affords extensive plains several thousand feet above the sea, and in North America the great plains gradually rise towards the north and west till they assume the character of plateaux.

Of these plains some portions are generally fertile, but very large tracts afford no traces of natural vegetation, and offer little promise. In some cases, rain is exceedingly rare.

61 *Mountain Systems of the Earth.*—The most elevated portion of the Earth's crust consists either of lofty ranges exhibiting a serrated or saw-like summit of jagged edges, rising directly from plains; of elevated ridges flanking table-lands; of ridges subordinate in height, having, notwithstanding, important physical characters; or of isolated peaks, or cones, not connected by intervening high ground. It is important to understand the term 'mountain chain' as being independent either of absolute or relative height either above the sea level, or with respect to adjacent plains, for there may be ridges of very low elevation which are in the strict sense mountains, and there are, on the other hand, many ranges of hills which are properly so called, although far more lofty than many mountain chains,* the mountain character not depending on absolute height above a fixed level, but rather on distinct physical features. Mountain chains also may and do extend far out to sea beyond their prominent and lofty ridges, and in this and many other ways are highly important and very distinct features of the Earth, greatly affecting its condition as the habitation of organic beings.

Strictly speaking, there are but two great systems of mountains on the globe, one in each great continent, although there may also be traced a multitude of others, some parallel to, and some making angles with, the principal directions. The mountain chain of the Old World, or Eastern Continent, has its main axis running east-north-east and west-south-west, while that of the New, or Western Continent, is north-north-west and south-south-east. The length of the former is about 9000 miles, and that of the latter 10,000 miles. The one rises in its highest part to not less than 28,000 feet, while the other nowhere attains a greater elevation than about

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* It is also important to remember that a mountain range is not necessarily a water-shed, nor does a water-shed require mountain country.

25,250 feet. The height of the elevated land thus bears some general proportion to the whole mass of land above the sea level.

There are certain features common to all mountain chains, which it may be well to consider before passing to the particular ranges themselves. They are rarely simple, but consist of distinct and often short ridges of high ground, running in the same direction, and nearly parallel to each other, rising at intervals to culminating peaks by the union of several convergent or radiating ridges. They exhibit also from time to time narrow transverse branches, or spurs, often of very great altitude, and forming, in fact, transverse mountain chains, which stretch far into the plains beyond.

The two sides of great mountain chains generally differ much in the rate at which they are inclined to the horizon, the one side being much more precipitous than the other. In the mountain chain of the Old World, for example, the southern side is generally scarped, and the northern side sloped, while in the Andes, the western side descends almost precipitously to the Pacific, while towards the Atlantic the slope is comparatively slow.

The mass of land, as measured by the relative elevation of different portions above the sea, has been made the groundwork of calculations whose object is to determine the mean height of various continental and other areas, and an enumeration of the effect of the various parts on the whole, as exhibited in the way of adding to the mean elevation, is one means of ascertaining the relative importance of mountain chains and other elevated districts.

The position of the mean height of all the solid parts of the Earth's crust above the sea, has been estimated by Humboldt at about 1000 feet; that of all Europe, 671 feet; of Asia, 1132 feet; of South America, 1151 feet; and of North America only 748 feet.

The effect of the plateau of Spain on all Europe, measured in this way, is estimated at 36 feet, while that of the whole chain of the Alps is only 20 feet. In Asia, the great central plains are estimated to contribute 120 feet of elevation. These results are, of course, only approximate.

62 *The General Connexion of the Mountains of the Old World.*—The great mountain system of the eastern hemisphere may now be described a little more in detail. Commencing with the western boundary of land at the Atlantic, we find the Atlas chain in Africa, the central Spanish mountains and the Pyrenees in Europe, nearly parallel to each other, and each connected with very lofty ranges further east, but all at length uniting and forming the commencement of the great Asiatic range, of which the Himalayan chain is the central and loftiest portion.

The Atlas range is lofty, complicated, and important, and forms a broad belt, having three principal divisions, which occupy the whole interval between the Sahara and the Mediterranean. The loftiest portion is the most inland, and forms, in Morocco, a mountain knot 15,000 feet high; the other portions are less elevated. The crest of the range is composed of granite and crystalline rocks, but the flanks are of stratified deposits of newer date.

The Spanish peninsula is almost entirely occupied by the table-land already described, and parallel ridges of serrated mountain peaks, terminated northwards by the Pyrenees; the latter being a chain of considerable elevation, the mean height of whose summit line is about 7000 feet. On the whole, this western extremity of the great mountain system of the Old World is remarkable for its great breadth and for the way in which it projects into the Atlantic, rather than for its altitude above the sea level.

The Pyrenees are continued eastwards at first by inconsiderable elevations and low table-lands, but these soon connect themselves with the western extremity of the Alps, whence the ground ascends rapidly by successive chains of mountains, commencing with the lofty range of which Mont Blanc and Monte Rosa are culminating points, extending through the various ranges of the Oberland, the Tyrolese, the Julian, the Noric, and other Alps, into the Balkan, and stretching southwards by very important spurs, of which the

Apennines and the mountains of Dalmatia are the most considerable, but of which other traces are also seen in the islands of Sardinia and Corsica.

The subsidiary ranges, whether parallel to or diverging from the principal chain of the Alps, include between them a somewhat extensive tract of low ground, and also a certain amount of higher table-land, but the position of the mountain chains, and their height above the sea, are the only points to which we now refer. These mountain chains consist, not only of those already mentioned, but also of the Jura (a somewhat transverse chain, subsidiary to the Alps,) and the Carpathians, which, turning southwards, partly complete the range towards the east, and partly connect the European mountain system with that of Asia. This communication is effected by the elevated land of the Crimea, conducting the Carpathians to the Caucasus; by the Balkan, passing into Asia Minor; by the mountains called Anti-Taurus; and also by the Taurus chain, which, by distant though appreciable links in Sicily, Crete, and Greece, connects the south Spanish mountain ridges with those of Asia Minor. In this way there appear to be in the European system three principal and nearly parallel ranges, the northern one being the loftiest. There are also several important subsidiary ranges, and one principal transverse range, that of the Scandinavian chain, running north and south, but of considerable altitude compared with the Alps and other lofty mountain chains. There are four principal and parallel chains that intersect the interior of Asia, following with tolerable regularity an east and west direction, and connected by transverse elevations at a few detached points: these are the Altai, the Thian-schan, the Kuen-lin, and the Himalaya. There are also four or more running north and south, of which the Ural, the Bolor, and the Khingan, are three, and the fourth is Chinese.

63 *General Outline of the Mountain Chains of the New World.*—The mountain systems of the western continent are fewer, more simple, and more readily traced than those of Europe, Asia, and Africa. The mass of land being much longer in proportion to its area, and the outline of the land on the whole less broken, no doubt contribute to this, but the comparative simplicity of geological structure is not without an important bearing on this condition.

The Rocky Mountains, which begin on the shores of the Arctic Ocean, nearly under the 70th parallel, commence the American system, and connect it by islands with that of Asia. They continue south-eastwards in an unbroken line, separated only by the plains near the north end of the Gulf of California, from the high plateau of Mexico. These lands, themselves very lofty, support also some high ridges and peaks, occupying the country as far as the Isthmus of Panama, where hills of low elevation, piercing through low plains, intervene before the commencement of the Andes.

The Andes.—This great chain may be considered as commencing with the plains of Mexico, at the point where the Rocky Mountain system ceases to be traceable, and passing through the narrow strip of land which separates the two Americas by means of the volcanic range of Guatemala. The chain enters South America at the Isthmus of Panama, and continues in a steady and almost unbroken line of high elevation, forming successively the Andes of Colombia and Quito, of Peru and Bolivia, of Chile, and of Patagonia, sinking down into the ocean beyond the southern extremity of Tierra del Fuego, after having traversed the whole continent from north to south, a distance of 4500 miles.

The general character of the Andes is that of a number of parallel mountain chains of great elevation and small breadth, often uniting into knots, and often containing between them plains of vast elevation and considerable extent; but this character is not seen so strikingly in the southern as in the northern portion of the country, so that for 2000 miles, or from Cape Hoorn to the parallel of 20° south, the chain is single, narrow, and uniform.

Besides the main and continuous chains of the Rocky Mountains and the Andes, there are also in North America the Alleghanies, or Appalachian chain, and in South America those of Guiana and Brazil, which appear to be independent; besides that of Venezuela, which is an eastern branch or spur of the principal range of the Andes.

The Appalachian, or Alleghany Mountains, consist of a series of low undulations of nearly uniform elevation and parallel to each other, rarely more than 3000 or 4000 feet high, extending under various names in a north-easterly direction, from about 35° north latitude to the mouth of the St. Lawrence and the coast of Labrador. The eastern range is known, in its course northwards, under the names of the Blue, the Catskill, and the Green Mountains, respectively. The breadth of the range is generally from 100 to 150 miles.

As subsidiary mountains of South America we must mention here the great system of Parime and that of Brazil. The former of these is a group of not less than seven chains of low mountain elevations, rising generally to a moderate height above the plain (which is 2000 feet above the sea), but having some much loftier elevations, of which an inaccessible peak, Mount Marivaca (10,500 feet high), is the most remarkable. The Brazilian mountains, so far as they are known, consist of ranges running north-east and south-west, of which the highest peaks rarely attain to the height of 6000 feet, and which average only from two to three thousand.

Between the two Americas, and in the line of the principal islands known as the Great Antilles (Cuba, St. Domingo, and Porto Rico), there is an important mountain system, running west-north-west and east-north-east, parallel to a similar range of less elevation, rising above the sea only in Jamaica. Of these, the mountains of Cuba rise to the height of 8000 feet, and those of St. Domingo to 9000 feet, while the elevations in Porto Rico are less considerable. The Jamaica mountains form a very sharp east and west ridge, running across the island at an elevation of from 5000 to 6000 feet, while some of the transverse spurs are as much as 7000 feet high.

64 *Mountain Systems of Australasia.*—It now only remains to describe in a few words the chief physical peculiarities exhibited in the mountain systems of the vast group of islands in Australasia. Australia itself, the chief mass of land in this district, exhibits apparently the same characters of table-land that are presented in Africa; where the extent of the land is large, the elevation tolerably uniform, and the coasts little broken into deep and narrow inlets. In other words, it presents sudden and precipitous mountain ranges towards the coast, which are not repeated inland, but slope gradually towards the interior. Thus, in New South Wales generally, and especially in the south-eastern part of this district, there is a north and south mountain range, which seems to be situate about 100 miles from the shore, and which rises to a height varying from 3000 to 6000 feet and upwards. In South Australia there is a similar range near Adelaide traced for some distance. The mountain systems in other parts of the Archipelago are little known, except that in New Zealand there is a range nearly parallel with that of New South Wales.

In addition to the great mountain systems traceable for considerable distances on the Earth's surface, there are in many places detached mountains, or groups of mountains, chiefly volcanic, either rising directly from the sea, or from extensive flat and often elevated plains. These being all connected with that reaction of the interior of the Earth on its exterior, which it will be convenient to consider under a distinct head, are for the present neglected in the account we have given of the plan of arrangement of those distinct mountain groups, which project in ridges above the general surface of the Earth's crust in a given district, whether that surface be above or below the level of the sea.

CHAPTER V.

HYDROLOGY.

§ 65. General phenomena of the ocean.—66. Action of the wind on the ocean.—67. The tides.—68. The Atlantic Ocean.—69. The Pacific Ocean.—70. The Indian Ocean.—71. The Arctic Ocean.—72. Marine currents.—73. Whirlpools.—Calms.—74. Inland salt seas. Bays, and gulfs.—75. Springs.—76. River basins.—77. River systems of the Atlantic group.—78. River systems of inland seas of the Atlantic.—79. Rivers of the Asiatic system.—80. River systems of the Pacific Ocean.—81. River systems of the Indian Ocean.—82. Rivers not communicating with the ocean.

GENERAL Phenomena of the Ocean.—The principal part of the water on the globe occupies large depressions on the solid surface, known under the name of *Oceans*. These are connected together by comparatively narrow passages, and are therefore really united, forming one wide and continuous expanse of sea. The different parts are, notwithstanding, known by distinct names, the most important being the Atlantic, Pacific, Indian, and Arctic Oceans. There are also some internal seas, or lakes, of considerable extent, as the Mediterranean, the Baltic, and others, which are almost entirely enclosed by land, and are filled with salt water, besides the great gulfs and bays of North America, and others better known, but far less extensive in Europe.

It appears by calculation, that the actual surface of the globe being reckoned at about 197,000,000 square British statute miles, as much as 145,000,000 square miles are covered by the waters of the ocean. It appears further, that out of about ninety millions of square miles of surface in the South half of the torrid zone and the South temperate zone together (the space between the equator and the Antarctic circle), nearly seventy-seven millions of square miles (almost seven-eighths) are water, while in the North temperate zone, the quantity of land is nearly equal to that of water. It is, therefore, evident that a great irregularity prevails in the distribution of land, and no reason has been suggested why this particular arrangement, rather than any other, has resulted. One consequence of this distribution of the water will be seen when we consider the phenomena of the tidal wave.

The depth of the ocean varies exceedingly, and its bed is broken, like the surface of the land, into plateaux, forming shoals, and ranges of mountains as well as isolated mountains, appearing above the surface in islands, and groups of islands. The structure also of the land is often continued into the sea, beyond the extremities of continents, as in the Agulhas bank beyond the south extremity of Africa, and also the islands of Tierra del Fuego. In other cases, there is a rapid and very complete termination of the high ground on the coast in the course of a very small distance. Many parts of the ocean have been fathomed, but in some places a line, whose length nearly equals the elevation of the loftiest peaks of the Himalayan chain, has failed to reach the bottom. Around our own coast the depth is very variable, not amounting to one hundred feet over great part of the German Ocean, while towards Norway, where the shore is bold, the depth is more than five thousand feet at a very short distance from the coast. The deep water commences also at a short distance from the shores of Ireland.

The ocean, over all parts of the Earth, contains a certain proportion of salt, which is not the same, however, for different seas, and even varies in different seasons and at various depths. The proportion is generally about three or four per cent., but is larger in the southern than the northern hemisphere, and in the Atlantic than the Pacific. The greatest proportion in the Pacific is in latitude 22° N. and 170° S. of the equator, and the smallest is in the Polar Seas, where the saltness is affected by the melting of the Polar ice. The surface is often less salt than the deeper parts of the sea, owing to the flowing into the ocean of large quantities of fresh water from rivers. In this case, the fresh water being lighter, floats on the surface for a long distance before becoming thoroughly mixed. Deep seas are generally more saline than those that are shallow, and inland seas than the open ocean, but this is not invariably the case, as it depends on the proportion that the river-water flowing into the sea bears to the evaporation from its surface, and also partly to the influx of salt water. Thus, the Mediterranean, especially in the deeper parts, is much more salt than the open sea, but the Baltic is much less so.

The temperature of the water is generally different from that of the atmosphere above it, and is greatly affected by depth and local circumstances. The temperature of deep water is constant, and in most parts of the ocean, within the temperate and torrid zones, is much lower than that of the surface.* The temperature diminishes, however, very irregularly in different seas, being so unequal, that one degree of the thermometer (Fahrenheit) answers sometimes to seven, and at other times to fourteen, fathoms depth, and even more. Still it has been considered, that in general the temperature decreases six times as rapidly in the sea as in the atmosphere, and thus we much sooner arrive at the stratum of invariable temperature (a limit which corresponds to 'the snow line' in ascending into the atmosphere). Under the equator this stratum is at the depth of 1200 fathoms—thence it rises towards the surface, and reaches it in the southern hemisphere (where the water is most open) in latitude 56° 26′, and then gradually descends again to latitude 70°, where it is 4500 feet below the surface. The temperature in the latitude mentioned is 39° 5′ at all depths. At the equator, the water at the surface is at 80° Fahrenheit, and therefore much above that of the stratum of invariable temperature; but at the pole, on the other hand, the water is much colder at the surface than at the depth mentioned above. Submarine currents setting from the pole to the equator, returning at a higher level to the pole, are concerned in the production of this condition.

66 *Action of Wind on the Ocean.*—The sea is constantly undergoing a certain amount of movement, produced by various causes, some of which, and these among the most remarkable, are external to our planet, although producing results upon it of the greatest possible importance. Others are connected with the mere surface action of the atmosphere when disturbed, and moving rapidly over the water, striking it at an angle. These results, producing what are called wind and storm waves, have been well described in a recent work on *Physical Geography* by Mrs. Somerville, and as she has expressed in a few words all the most striking phenomena on this subject at present known, we cannot do better than borrow her words:—

'Raised by the moon and modified by the sun in the equatorial seas, the central area of the two oceans is occupied by a great tidal wave, which oscillates continually, keeping time with the returns of the moon, having its motion kept up by her attraction acting at each return.

'The friction of the wind, however, combines with the tides in agitating the surface of the ocean, and, according to the theory of undulations, each produces its effect independently of the other; wind, however, not only raises waves, but causes a transfer of superficial water also. Attraction between the particles of air and water, as well as the pressure of the atmosphere, brings its lower stratum into adhesive contact with the surface of the sea. If the motion of the wind be parallel to the surface, there will still be

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* This, however, is not everywhere the case, for Humboldt observed, in crossing from Corunna to Ferrol, that the surface water varied from 54½° to 56° Fahrenheit, while the deep water was 59° to 59½°, and the atmosphere 55°.

friction, but the water will be smooth as a mirror; but if it be inclined, in however small a degree, a ripple will appear. This friction raises a minute wave, whose elevation protects the water beyond it from the wind, which consequently impinges on the surface at a small angle: thus, each impulse combining with the other, produces an undulation which continually advances. Those beautiful silvery streaks on the surface of a tranquil sea, called cats-paws by sailors, are owing to partial deviation of the wind from a horizontal direction. The resistance of the water increases with the strength and inclination of the wind. The agitation at first extends little below the surface, but, in long-continued gales, even the deep water is troubled; the billows rise higher and higher; and as the surface of the sea is driven before the wind, their 'monstrous heads,' impelled beyond the perpendicular, fall in wreathes of foam. Sometimes several waves overtake one another, and form a sublime and awful sea.

'The highest waves known are those which occur during a north-west gale off the Cape of Good Hope, aptly called the Cape of Storms by ancient Portuguese navigators; and Cape Hoorn seems to be the abode of the tempest. The sublimity of the scene, united to the threatened danger, naturally leads to an over-estimate of the magnitude of the waves, which appear to rise mountains high, as they are proverbially said to do. There is, however, reason to doubt if the highest waves off the Cape of Good Hope exceed forty feet from the hollow trough to the summit. They are said to rise twenty feet off Australia, and sixteen feet in the Mediterranean. The waves are short and abrupt in small shallow seas, and on that account are more dangerous than the long rolling billows of the wide ocean. The undulation, called a ground-swell, occasioned by the continuance of a heavy gale, is totally different from the tossing of the billows, which are confined to the area vexed by the wind, whereas the ground-swell is rapidly transmitted through the ocean to regions far beyond the direct influence of the gale that raised it, and it continues to heave the smooth and glassy surface of the deep long after the wind and the billows are at rest. A swell frequently comes from a quarter in direct opposition to the wind, and sometimes from various points of the compass at the same time, producing a vast commotion even in a dead calm, without ruffling the surface. Waves are the heralds that point out to the mariner the distant region where the tempest has howled, and they are not unfrequently the harbinger of its approach.

'In addition to the other dangers from polar ice, there is always a swell at its margin. Heavy swells are propagated through the ocean, till they gradually subside from the friction of the water, or till the undulation is checked by the resistance of land, when they roll in surf to the shore, or dash in spray and foam over rocks. The rollers at the Cape de Verde Islands are seen at a great distance, approaching like mountains. When a gale is added to a ground swell, the commotion is great, and the force of the surge tremendous, tossing huge masses of rock, and shaking the cliffs to their foundation. The violence of the tempest is sometimes so intense as to quell the billows and blow the water out of the sea, driving it in a heavy shower, called spoon-drift by sailors. On such occasions, saline particles have impregnated the air to the distance of fifty miles inland. The effect of a gale descends to a comparatively small distance below the surface; the sea is probably tranquil at the depth of 200 or 300 feet: were it not so, the water would be turbid and shell-fish would be destroyed. Anything that diminishes the friction of the wind smoothes the surface of the sea: for example, oil, or a small stream of packed ice, which suppresses even a swell. When the air is moist, its attraction for water is diminished, and, consequently, so is the friction; hence the sea is not so rough in rainy as in dry weather.'*

67 *The Tides.*—We have already mentioned the fact of the existence of a great tidal wave oscillating continually, and produced by the periodical

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* Somerville's *Physical Geography*, 1st edition, p. 239.

movements of our satellite the moon. If the Earth presented a uniform globe, with a belt of sea of great and uniform depth encircling it round the equator, this wave would be perfectly regular and uniform. The sun carrying with it one such wave, and the moon another, there would be four tides, so modified, however, as to produce two principal ones compounded of the four. The actual case is, however, very different from this imaginary condition, so that the heights of successive tides vary, indeed, in some proportion to the way they would do in the simpler case, but the direction of motion and the state of high water are exceedingly various. It is very difficult to form an adequate notion of tidal phenomena, without elaborate tidal charts, the materials for which have only been partially accumulated; but we may by description give some idea of the true case. Looking at a globe or map of the world, we observe no uniform belt of sea round the equator; but on the contrary, the great continents cross the equator at nearly right angles, the Atlantic Ocean remaining as a comparatively narrow basin, while the Pacific is greatly intercepted by coral reefs, islands, and sunken continents. In point of fact, the great reservoir of water in which regular tidal action occurs, is not only in the southern hemisphere, but nearer the Antarctic circle than the equator. The source of the tides is therefore to be sought in the expanse of sea occurring within the south temperate zone, where the great central agitation seems to commence, and whence on all sides it appears to flow northwards. The Atlantic thus receives from the south its great wave of tide, which gradually becomes a curve, whose convexity is more and more northwards, until after passing the tropic of Cancer, the advance of the wave is so greatly retarded on the coast by the narrowness of the channel, that a portion of it has reached the latitude of the southern extremity of Greenland by the time that another portion has scarcely passed Cape Blanco on the African coast, and Cuba in the West Indies. The great wave of tide passing northwards, in this narrow channel, thus forms an enormous stream tide on the shores of Britain and North America, but it has, by this time, become so complicated, that it is difficult to trace its relations with the moderate and regular undulation produced originally by the attraction of the moon. So also in the Pacific, the tide is so checked by the sub-marine irregularities of surface, that for a considerable part of that vast ocean, there is scarcely any wave of the kind exhibited. In the Indian Ocean, on the other hand, the tide wave, little interrupted by such causes, makes its way in an irregular curve to the shores of India, and there divided by the pyramidal form of the peninsula of Hindostan, one portion proceeds up the Bay of Bengal, and the other towards the Persian Gulf; the former having no escape, and not dissipated by irregularities in the form of the land, gradually increases in height as the bay narrows, and finally reaches the mouth of the Ganges, where it expends its force on the shores in the form of the well known and terrific *bore* of the Hooghly. In point of fact, therefore, the tides, although formed entirely by the attraction of the sun and moon, by no means follow the apparent course of those bodies after their original genesis. After the wave has once entered the canal of the Atlantic, it moves continuously northwards, with very various velocity, but at first at the rate of nearly a thousand miles per hour. In the first twenty-four hours, it has brought high water to Cape Blanco on the west of Africa, and Newfoundland on the American continent. In the morning of the second day, this great wave having been driven eastwards, reaches the western coast of Ireland and England. Passing round the northern Cape of Scotland, it reaches Aberdeen at noon, travelling in precisely the opposite direction to that of its first progress, and also opposite that of the sun and moon. Still proceeding onwards, at midnight of the second day, it reaches the mouth of the Thames, and on the morning of the third day brings the merchandise of the world to the port of London. It thus takes more time to reach London from Aberdeen than to pass over an arc of 120°, (8000 miles,) between 60° south latitude and 60° north. The velocity of the progress of this wave is greatest where the water is deepest, and where the configuration of the shores offers the fewest obstacles.

68 *The Atlantic Ocean.*—We must now consider those phenomena that are peculiar to the different parts of the great Ocean. The *Atlantic*, although its boundaries are not completely marked by nature, is yet perfectly distinct and easily described. It is that area of water occupying the space between the western shores of the Old and the eastern shores of the New World, and reaching from the Arctic circle to the icy shores of the Antarctic land. The limit to east and west beyond the land of the two continents to southward (in latitude 34° and 55° S. respectively,) is considered to be a continuation of the meridian of longitude of the Cape of Good Hope and Cape Hoorn, (20° E. and 70° W. from Greenwich). This ocean, including its inland seas, covers about thirty millions of square (British statute) miles.

Extending thus for nearly 140 degrees of latitude, the breadth of the Atlantic will be seen to be comparatively small. The two continents which form its shores approach nearest one another between Greenland and Norway, in latitude 69°—71°, and are there only 800 miles apart. Widening gradually, but then again contracting, the breadth about 5° S. of the equator, between Brazil and Sierra Leone, in Africa, is still only 1500 miles. At 30° N. latitude, where its breadth is greatest, (between Florida and the coast of Africa,) the width is 3600 miles.

The elongated valley form of this ocean long since attracted the attention of Humboldt, who observed that not only do the projections and protuberances of one coast correspond with recesses on the other, but that the nature of the mountains and plains also corresponds. This is chiefly the case with regard to Africa on the east, and the northern part of South America on the west. There are few mountains in the bed of the Atlantic, or, at least, few that show themselves as islands above its surface. The principal of these form volcanic islands and groups, and, except those in the northern part and the West Indian group, are placed near the shores of Africa, and are probably the last indications westward of the great mountain system crossing the Old World.

The depth of the Atlantic is in some parts very considerable. In latitude 27° 26′ S., longitude 17° 29′ W., it was sounded by Sir James Ross, and found to be 14,550 feet; 450 miles west of the Cape of Good Hope it was 16,062 feet, (332 feet more than the height of Mont Blanc;) while in latitude 15° 3′ S., and longitude 23° 14′ W., a line of 27,600 feet failed to reach the bottom.

The form of the land on the northern shores of the Atlantic is worthy of notice, having a tendency to linear extension, not only in the several islands of Nova Zembla, Spitzbergen, and Greenland, but also the main land of Norway, which is split as it were into shreds by deep inlets (*fjords*). Scotland exhibits, in its northern and western islands, a similar peculiarity of form. The shores of this ocean are also very deeply indented by large seas, of which the Baltic and the Mediterranean are the most remarkable.

In consequence of the contorted and complicated line which the shores make, the length of coast enclosing the Atlantic is very considerable, and is indeed much more so than that of the Pacific, notwithstanding the far greater magnitude of the latter ocean. The eastern coast line of the Atlantic is 32,000 miles in length, and the western, or American, 23,000 miles, making a total of 55,000 miles.

The Atlantic receives the rivers of a certain portion of the land enclosing it, and the area of each river basin includes all that land the water of which naturally flows into the river. In Europe and Africa, there are no rivers of first-rate magnitude emptying themselves directly into the Atlantic, since the Rhine, the largest of them, has a course of only 700 miles, while the Nile, the Danube, the Dnieper, the Rhone, and others, run into the Mediterranean, the Volga into the Caspian, and the Elbe and Oder into the Baltic. On the American side numerous gigantic rivers pour directly into the Atlantic a vast body of water, draining almost the whole of the New World.

There are several exceedingly important currents in the Atlantic, but these will be best considered after we have described the phenomena of the

Pacific and Indian Ocean. The winds of the Atlantic have been already the subject of some notice in speaking of atmospheric influences.

A very extensive area of the Atlantic, extending from 19° to 36° N. latitude and from 30° W. longitude to the Bahama Islands, (occupying in all 360,000 square miles,) is covered at intervals with a species of marine plant, (*fucus natans*,) called sometimes the *sargasso*, or *gulf-weed*. The quantity of marine vegetation, and consequently of animal life, in this vast range, especially in two principal fields near the termination of the Gulf Stream, and where two portions of the stream meet, is truly astonishing. The real origin of this accumulation is not known, but in its results it is sufficiently interesting, as it affords food and shelter to a multitude of marine animals. The Atlantic Ocean is divided by geographers into two portions—one north, the other south of the equator, and called, therefore, respectively the North and South Atlantic Ocean. There is no natural division corresponding to this artificial arrangement.

69 *Pacific Ocean.*—The Pacific Ocean covers more than half the surface of the globe, and its area may be roughly estimated at ninety millions of square miles, occupying the space between the shores of America on the one side, and the coasts of Asia and Australia on the other. Its northern boundary is Behring's Straits, which, between East Cape, in Asia, and Cape Prince of Wales, is not so much as forty miles wide; but from this point the coasts rapidly diverge, and at 54° 30′ N. latitude, between the peninsula of Alashka and Kamtschatka, are more than 1200 miles apart. Continuing to diverge, the breadth from California to the coast of China, on the tropic of Cancer, is 8500 miles; and this remains pretty constant as far as the south tropic, where the distance from Sand Cape in Australia to the coast of Chile is 8200 miles. Towards the southern extremity, the limits of the Pacific are understood to be the meridians of longitude passing through Cape Hoorn and South West Cape, in Tasmania, and the ocean terminates, as the Atlantic does, at the icy shores of the Antarctic land.

The Asiatic border of the Pacific is fringed in a very remarkable manner with islands, almost enclosing a range of seas, or small basins, which correspond with and replace the deep inland seas of the Atlantic. Long peninsulas also project from the main land, and these, as well as the islands, (and the coast itself where they do not occur,) are dotted at intervals with active volcanoes, of which a very large proportion of the whole number known on the globe are there placed. Although, however, the Asiatic and North American coasts are much broken, the South American is for the most part bold and rocky. The total length of the coast line, including that of the whole Indian Ocean, is estimated at 47,000 miles, about 8000 miles less than that of the Atlantic.

While the south-western and western portions of the Pacific are so thickly strewn with islands that the number of them is not at all known, even approximately, the eastern, northern, and southern portions are singularly free from islands, the sea for fifty degrees of longitude west of the American coast (exceeding very greatly the whole Atlantic in extent,) having only one group of any importance, (the Galapagos,) and that extremely small. Of the island district, which extends chiefly between the tropics, and reaches from the west boundary of the ocean to longitude 135° W., there are two principal groups, the one consisting of flat, low islands, in groups more or less connected with sunk coral reefs, often of great depth, and the other of high and volcanic islands, occasionally surrounded with a fringe of shallow coral. A space extending more than 1000 miles in length and 600 in breadth, south of New Guinea, and between the north-eastern coast of Australia and the New Hebrides group, is remarkable for the innumerable multitude of coral reefs, islands, and banks it encloses, and this may possibly be the last remains of a sunken continent, of which the eastern part of Australia, New Guinea, and other islands formed a part, but which has now almost entirely disappeared over a large portion of its area. The Pacific would appear to possess a depth corresponding in some degree to its vast area.

70 *Indian Ocean.*—That portion of the great ocean which extends southwards from Asia to the Antarctic Circle, and eastwards from Africa to Australia, thus occupying the interval between the Atlantic and Pacific, is called the Indian Ocean. Including the Red Sea, Persian Gulf, Bay of Bengal, &c., it occupies an area of about 23,000,000 of square miles, and is thus nearly as large as the Atlantic itself. It includes several very large and important islands, as Madagascar, Borneo, Sumatra, Java, Ceylon, &c., and some important systems of islands, and it receives the drainage of several of the principal river-basins of Asia, as the Ganges, Brahmapootra, Indus, and Euphrates. The chief points of interest connected with this ocean have reference to its currents.

71 *Arctic Ocean.*—The tract of sea within the Arctic Circle, bounded by the northern coasts of Europe, Asia, and America, includes an area of about 3,000,000 of square miles, and is called the Arctic Ocean, or Icy Sea. It is connected with the Pacific by Behring's Straits, and with the Atlantic by the wide strait between Greenland and Norway. The corresponding tract of ocean at the opposite pole is called the Antarctic Ocean, and is estimated to occupy about 2,000,000 square miles. Its exact limits have not been very accurately determined, as the ice extends much further from the south than it does from the north pole.

72 *Marine Currents.*—The water of the sea is not only constantly kept in motion by the attraction of the sun and moon, producing the tidal waves, and by occasional disturbances the result of winds, but there are also large bodies of water, as well in closed seas as in the open ocean; which are continually moving onwards in a fixed and constant direction, some of them depending on causes not less permanent than the globe itself, and others, although originated by the form of land and local influences, remaining constant for periods of time far longer than any records of man can reach. There are also periodical currents of greater and less importance.

Of these various currents, some are merely superficial, slow in their motion, easily turned aside by natural obstacles, such as sand-banks, projecting headlands, &c., and resulting generally from constant winds; others are deep, broad, and sometimes even rapid; their temperature is different from that of the ocean through which they make their way, and they proceed like rivers through a great continent, keeping a course which sometimes extends for thousands of miles. The former are called drift currents, the latter stream currents. The most important of the stream currents are those which occur in the Atlantic, or, at least, it may be considered that, as these are best known and most affect navigation, they require the most extended notice. Many of these currents, however, commence in other seas, and thus connect the waters of different parts of the great ocean. Thus, the Gulf Stream, perhaps the most important of all, must be regarded as originating in the Indian Ocean or even in the Pacific, and the Arctic currents bring ice and cold water far into the Atlantic from the Arctic Ocean. Omitting, for the present, those currents which have their origin in the waters which pour into the sea from the great rivers of the Earth, we will consider now the principal marine currents in their relation with one another.

Commencing in the northern part of the Bay of Bengal, a current sets southwards for some distance, and passing round the south of Ceylon, turns westwards to near the coast of Africa. This current, however, depends upon the monsoon, being a northerly current during the south-west monsoon, from February to October, and southerly during the rest of the year. Between Madagascar and the mainland of Africa there sets another current, which, under the name of the *Mozambique Current,* continues close along the African coast in a south-westerly direction during the whole year. A little farther south it becomes a true southerly current, having near the coast a mean velocity of from 18 to 20 miles per day, which at some seasons is greatly exceeded, a case having been known of a ship drifted by this current 139 miles in 21 hours, a velocity only paralleled in the maximum of the Gulf Stream. Near Algoa Bay, and off the Agulhas Bank, this current passes into the *Cape*

Current, which is formed, indeed, of its junction with the currents from the seas south of Madagascar. A part of the Cape Current is deflected by the Agulhas Bank, and passes round by the Cape of Good Hope into the *South Atlantic Current,* but the main portion turns southwards in latitude 21° to 24°, and then, passing eastwards, forms an important counter-current, mixing with the *South Atlantic Counter Current.*

The Cape Current is from 90 to 100 miles broad, and in different parts of its course flows at the rate of from 60 to 100 miles per day. Outside the Agulhas Bank the temperature has been observed to be about 80° above that of the ocean. The counter current running eastward has a breadth of from 200 to 240 miles, and a velocity of 50 miles per day.

The South Atlantic Current is a continuation of the Cape Current towards the north and north-west, along the coast of Africa. In latitude 10° south it has ceased to be traceable at the surface, and then commences the *Main Equatorial Current.* This important part of the stream currents of the Atlantic may be distinctly recognised off the coast of Africa, a little south of the equator. It runs nearly on the equator, and parallel with another (the *Guinea Current*), which terminates a little to the north, near the mouth of the Niger; and for a distance of more than 1000 miles these two currents exhibit the remarkable phenomenon of parallel streams in contact with each other, flowing with great velocity in opposite directions, and having a difference of temperature of 10° or 12°. The Main Equatorial Current proceeds on both sides of the equator to 22° west longitude, and then sends off the *North-west Branch Current,* and, declining to the south, runs parallel with the coast of South America beyond the tropic of Capricorn. At Cape St. Roque, however, a portion of the stream runs parallel to the northern coast of South America, till it disappears near the mouth of the Amazons, being covered and crossed by the volume of fresh water proceeding from that river. The north-west branch of this current flows at first north-westwards, and afterwards towards the north, till, in about 30° north latitude, it merges in a drift current; its breadth varies from 200 to 300 miles. The length of the Main Equatorial Current, measured from the coast of Africa to its termination near the Caribbean Sea, is about 4000 miles; and that of the *Brazil Current,* its southern portion on the coast of America, is nearly 1000 miles; its breadth at the commencement is about 160 miles, at about 5° west longitude it has increased to 360 miles, and at the point of separation of the north-west branch amounts to 450 miles. The mean velocity of the whole course of the current may be reckoned at 36 miles per day, but between 10° and 16° west longitude in the summer season, it varies from 44 to 78 miles, and has even been recorded at 90 miles per day. The velocity of the north-west branch is much less, commencing at from 20 to 24 miles per day, and gradually diminishing. Throughout its course to the Caribbean Sea this is a cold current, the average temperature being from 4° to 6° below that of the ocean; its northern portion passes into what is called the *Guiana Current,* which extends about 500 miles, with a velocity varying from 10 to 36 miles per day. This current enters the Caribbean Sea, and is there lost sight of.

In addition to the currents already described, and uniting them between the Cape of Good Hope and the coast of Brazil, is the *Southern Connecting Current,* which is but little known, and flows chiefly to eastward about 150 miles south of the Cape of Good Hope, into the Indian Ocean. We have seen thus that a great body of water proceeds across the Atlantic from east to west, spreading out northwards and southwards as it approaches the great barrier of land presented by the continent of America. The form of this land, the vast recesses of the Caribbean Sea and the Gulf of Mexico, separated from the main ocean by the chain of the West Indian islands and the peninsula of Florida, conceal the further progress of these currents. But an important and very considerable current has been traced, setting round the Campeche Bank into the Gulf of Mexico, and assisted by the river current of the Missisippi passing out into the Atlantic between Florida and Cuba. Running within the Bahama Bank, the water thus issuing into the open ocean continues parallel with the coast of North America, till it meets the St. George and Nantucket banks, when its course is directed eastward. After passing the southern extremity of the bank of Newfoundland, it continues in the same direction to about 38° west longitude, between 35° and 43° north latitude, and at this point it turns to south-east and south, and, passing the westernmost of the Azores, is soon afterwards lost in the Atlantic. This remarkable and important stream-current is well known under the name of the *Gulf Stream*. It extends on the whole upwards of 3000 miles, and occupies 78 days in its progress, thus averaging a daily rate of 38 miles, but the velocity varies greatly, amounting to 120 miles per day at the end of the Gulf of Florida, and not more than 10 miles per day in the vicinity of the Azores. The maximum temperature of the stream is in the strait of Florida, and is then 86° or 89°, considerably above that of the ocean in the same latitude; 10° farther north, it is still as much as 84°; and, although both temperature and velocity decrease as the stream progresses, the temperature remains constantly very much above that of the ocean outside the current. It is the influence of this stream upon climate that renders the British islands green and fertile, while the shores of Labrador in the same latitude, or the shores of America, are fast bound in the fetters of ice; its influence is not therefore confined to the line of its direct course, but is felt along the shores of Europe even as far north as Spitzbergen. The Gulf Stream must be considered to terminate, as we have said, in about the 25th meridian of west longitude, but two other currents are traceable on the western coast of the Old World; one called *Rennel's Current*, commencing near Cape Finisterre, running northward along the coast of Spain, and thence along the west coast of France. After crossing the English and Irish channels, and the south coast of Ireland, this current enters the open ocean, and joins the other, or *North African Current*, which runs first southwards, following the coast of Africa, but then, continuing parallel with the shores of that continent, it turns eastwards, and forms that remarkable contrast to the Equatorial Current already alluded to. Rennel's Current has a velocity of about a mile an hour, in certain winds, and the North African Current about half that velocity in the northern part of its course, but afterwards a rate of as much as 50 miles per day.

The remaining Atlantic currents are two, the *Arctic Current*, and that which, passing round Cape Hoorn, may be regarded as an *Antarctic Current*. The former is understood to originate in the ice which surrounds the North Pole; it sets south-westwards, from between Iceland and Greenland, and arriving at Newfoundland, divides into two branches, the main stream passing between the great and outer bank of Newfoundland into the Gulf Stream, and afterwards again dividing, one portion flowing southwards to the Caribbean Sea, while the other forms the *United States Counter Current*, which extends between the Gulf Stream and the coast to Cape Hatteras and Florida; this current conveys southwards enormous masses of ice, bringing with them immense quantities of stone and earth, which are sometimes stranded in shallows or on banks, and sometimes, melting gradually, pass down into low latitudes, and temper the heat or chill the air of those countries along whose shores they pass. The *Cape Hoorn Current* is an easterly current along the southern extremity of America and the Falkland Islands, but it has originally proceeded from the Antarctic Polar Sea, and thus brings with it very large quantities of drifted ice. Its velocity appears to vary very greatly, from 12 to about 56 miles per day, and it probably mixes with the waters of the southern connecting current.

The currents of the Pacific Ocean are not so well known as those of the Atlantic, nor do they appear to be by any means so considerable or so important in navigation. The most interesting is that which, commencing as a drift current from the Antarctic Pole, near the newly discovered Victoria Land, becomes a coast current of cold water between latitude 40° and 50° south, and then runs northwards along the western coast of South America, lowering the temperature of the land, and apparently producing an effect exactly the converse of that which the Gulf Stream produces on the coast of Europe. At the surface this current is slow, often not amounting to more than a third of a mile per hour; but at the depth of from 12 to 15 fathoms it is more considerable and in the same direction. In some part of its course this current runs at the rate of 14 to 18 miles per day, and it is traceable along the coast from Valparaiso almost to the equator, when it turns westwards into the open ocean of the Pacific, but remains sensibly affecting the temperature to a distance of several thousand miles; the difference in temperature between the current and the mean annual temperature of the atmosphere is throughout considerable.

73 *Whirlpools.—Calms.*—Whirlpools are produced by opposing tides, winds, or currents, but the former most generally. They are rare in all seas, and not by any means so destructive now as they seem to have been in ancient times, when the principles of navigation were less understood.

Although the greater part of the ocean is disturbed constantly by these various causes, there are not wanting very extensive areas, especially within the tropics, and far from land, when dead calms prevail, and the sea remains for days in a state of unruffled stillness. The low flat tidal wave is then so large, and so regular in its heaving, that it seems lost, and thus an appearance of perfect quiet is presented.

74 *Inland Salt Seas.—Bays and Gulfs.*—Although we have already had occasion to allude to those deep inlets of the sea that occur in various parts of the world and form inland seas, it is still necessary to refer to them again in some little detail, to give an idea of their comparative dimensions and importance.

Of the inland seas connected with the Atlantic, the Mediterranean is the largest and the most beautiful. It occupies 950,000 square miles, but is nearly divided into two seas by the projecting land of Italy, continued by shallows to the opposite coast of Africa. The temperature of the water is higher by 10° or 12° than that of the Atlantic, and the evaporation is excessive. It is one consequence of this and of the comparative smallness of the river drainage emptying itself in the Mediterranean, that its waters are as much as four times as salt as the ocean. Many parts are exceedingly deep.

The Baltic is a long narrow inland sea, occupying about 200,000 square miles in the centre of northern Europe, and receiving the drainage of more than a fifth of the whole continent. Its depth nowhere exceeds 115 fathoms, and is generally not more than forty to fifty fathoms. It is one-fifth less salt than the ocean.

The Black Sea, the Sea of Azof, the Caspian, and the Aral, together form one depression, which is only partly filled with salt water. The whole area of water in the two former lakes is near 250,000 square miles, and in the Caspian 180,000 square miles. The waters are brackish; the depth, especially of the Caspian, is considerable, but decreases towards the shores gradually, and in terraces.

Baffin's Bay, twice the size of the Baltic, and Hudson's Bay, also of vast dimensions, penetrate the North American continent at Davis' Straits, while the Gulf of Mexico, occupying 800,000 square miles, and the Caribbean Sea, whose area is more than a million and a quarter miles, are still more extensive indentations nearer the equator, shut in by islands, and resembling in this respect the Yellow Sea, the China Sea, and the Sea of Japan, on the east coast of Asia.

75 *Springs.*—A glance at the distribution of water upon the Earth will show that there are two very distinct parts of the subject, one of which we have already considered—namely, the phenomena of the great mass of salt water forming the ocean and its branches,—while the other, relating to fresh water, still remains to be considered. This second group of phenomena is also twofold, including the sources whence the fresh water upon the Earth is derived, and also the brooks, streams, and rivers which convey the water across the land, and pour it into the sea. Lakes of fresh water, and other accumulations dependent on the form of land, also require some consideration.

The first commencement of running water upon the Earth's surface is generally from springs, which issue occasionally from hill sides, sometimes from crevices in the Earth of no great magnitude, but sufficient to allow of the out-pouring of a large body of water, and sometimes from large natural cavities in very considerable quantities. However little these different sources may seem to have reference to the rain falling on the surface of the Earth in their vicinity, they are, in fact, with very few and unimportant exceptions, thus derived. It is only a part of the rain that runs off directly from the surface into streams and rivers, and thus manifestly swells their magnitude; and although no doubt this quantity is increased by that portion which, falling as snow, and collected on mountain-tops in the colder parts of the year, is gradually melted in the warmer seasons, there still remains a very large proportion. A portion of this again is soon received into the atmosphere by evaporation, but a very considerable quantity sinks down within the crust of Earth, and is conveyed along underground, re-appearing in the springs already alluded to. The absolute quantity of rain falling upon the Earth is, as has been already stated (see *ante*, p. 210), exceedingly great, and that portion of it which runs off to the sea by means of rivers in the west of Europe, is supposed not to exceed one-third, although doubtless very much greater in climates where the rain falls more heavily. The proportion that sinks beneath the surface, and re-appears at a distance, must also be large, so that, on the whole, the actual circulation of fresh water upon the globe, evaporated from the ocean, conveyed through the air in clouds, and falling upon the land as rain, is important, not only as affecting the fertility of the Earth, and its adaptability as a habitation for organic beings, but also absolutely in its effect upon the physical features of the Earth. This latter subject will require careful consideration in a separate chapter.

76 *River Basins.*—It will be at once evident that so far as rivers depend for their supplies on the direct accessions they obtain from surface water, the whole area of the land may be divided into districts, each of which, in consequence of the form of the enclosing high ground, conveys all the water that falls upon that district, either into a depression within its area forming a lake, or into a channel which conducts the water to the ocean. The whole Earth may thus be divided into ocean beds and river basins. Almost all the running waters or rivers of the globe of considerable importance, communicate directly or indirectly with the ocean, sometimes, indeed, passing through and being apparently lost in lakes, but ultimately flowing into that grand receptacle which has supplied the water, and which must again receive it. This is not, however, invariably the case, and thus we have oceanic and continental systems of river basins. These are both so important that we must now proceed to consider them in some detail.

It is a well known fact, frequently determined by actual experiment, that a much larger quantity of rain, *cæteris paribus*, falls on hills and high plains than on the lower plains, and hence it arises that the high table-lands and mountains of every district are even more directly concerned in the natural drainage than might at first be supposed, and thus it also results that the water-shed, or that line along high ground which determines the ultimate direction of the rain that falls, is an important element in such considerations as those we are now entering upon. If we look upon a map of the world, or a good globe, we find there must be natural divisions forming those groups or basins to which we have alluded, and which, as we have already remarked, are of two kinds, one communicating immediately with the ocean, into which the rivers empty themselves, which may therefore be called *oceanic river systems*, including each of them a number of rivers; and another, including what may be called *continental river systems*, forming large basins, in which the drainage is confined entirely or chiefly within continental tracts of land, without proceeding to the ocean. In every case, the springs, brooks, and rivulets whose waters contribute to the formation of a single river, and the land which is drained by these various water-courses, form the area of drainage, and the line inclosing this area forms the water-shed.

We proceed now to consider the principal river basins in various parts of the world, and these we may regard as forming eight distinct groups—namely, the groups of the Atlantic, Pacific, Indian, and Arctic Oceans; those of the Black Sea, the Mediterranean, and the Caribbean inland seas, the latter including the Gulf of Mexico; and the great continental groups, of which the chief is in Central Asia, where a number of rivers empty themselves into the Caspian Sea, the Lake of Aral, and the lakes in the eastern part of Central Asia, in the desert of Gobi, without reaching the ocean.

77 *River Systems in the Atlantic Group.*—The Atlantic group includes a considerable number of river systems of great importance, both in Europe, Africa, and America, and the following table gives a connected view of the extent and relative importance of those amongst them which are best known.

PRINCIPAL RIVER SYSTEMS IN THE ATLANTIC GROUP.

NAMES OF RIVER SYSTEMS.	Extent of river basin in square miles. (Geographical.)	In Geographical Miles.		
		Direct distance of river from source to mouth.	Extent of development of stream.	Extent of windings of stream.
I. EUROPEAN RIVERS.				
Neva	67,200?	315?	440?	128
Rhine	65,280	360	600	240
Vistula	56,640	280	520	240
Elbe	41,860	344	684	340
Oder	39,040	280	480	200
Loire	33,940	320	520	200
Dwina	33,440	280	560	280
Niemen (Memmel)	32,180	240	460	220
Douro	29,250	260	440	180
Garonne	24,450	200	320	120
Seine	22,620	220	340	120
Tagus	21,760	360	480	120
Guadiana	19,360	240	420	180
Guadalquiver	15,040	180	260	80
Weser	13,120	200	280	80
Minho	11,840	108	192	56
Pregel	5,920	60	100	40
Thames	5,000	112	192	80
II. AMERICAN RIVERS.				
Marañon (Amazons)	1,512,000	1548	3080	1562
La Plata	886,400	1028	1920	892
St. Lawrence & Lakes	297,600	860	1800	940
Tocantins	284,480	990	1120	130
Orinoco	252,000	368?	1352	984
St. Francisco	187,200	872	1400	528
Paranahyba	115,200	560	744	184
Essequibo	61,650	350	420	70
Delaware	8,700	180	265	85
Connecticut	8,000	231	270	39

NOTE.—By the extent of development of a stream, is meant its length from source to mouth, including all its windings and turnings. This, compared with the direct distance between the source and the mouth, shows the amount of the windings, and enables us to determine the influence which the river exercises on its district. But to understand this, we have to consider not only the length of the principal channel, but also the surface extent of its tributary

Of the rivers mentioned in the above table, the *Rhine* takes its rise in the Alps from two principal sources; one of them on the north side of the St. Gothard, from a glacier at the height of 7650 feet, the other from the Rheinwald glacier, near St. Bernardin. The river has a rapid declivity to the Lake of Constance, on emerging from which, its bed is suddenly depressed at the celebrated falls of Schaffhausen, and the river then runs westward to Basle, whence, turning northwards, it is navigable to the German Ocean, being interrupted only in passing through the narrow defiles between Bingen and the town of Bonn. The chief tributaries to the Rhine are the Moselle, the Maine, the Necker, and the Meuse.

The *Elbe* rises on the western slopes of the Riesengebirge, from upwards of thirty springs, one of which has an elevation of 4500 feet, but the greater part of this river runs through a very flat country, and its estuary is encumbered by sand-banks.

The *Neva* is, with the exception of the Rhine and Rhone, the only important European river which is connected with considerable lakes. It rises in the hilly district extending between the Volga and the Dwina, and thence, under various names, proceeds northwards to the lakes Onega and Ladoga, entering the Gulf of Finland at St. Petersburgh. Although its river basin is of great extent compared with that of most of the European rivers, the Neva presents few points of interest in Physical Geography. The remaining European systems are also not remarkable for any physical peculiarities, and will be again alluded to in the Descriptive part of this work. The rivers of the British islands drain only small river basins, those of the Severn and Thames being somewhat smaller than that of Pregel; they also are chiefly interesting in reference to Descriptive and Political Geography.

It will be at once observed, on reference to the above table, that the river basins in the New World are enormously larger than those in the Old. The *Marañon*, or *Amazons*, alone, has for its area of drainage a district nearly three times as large as that of all the European rivers which empty themselves into the Atlantic; this vast river, the largest on the globe, is, in some places, six hundred feet deep, it is navigable more than two thousand miles from its source, and is nearly one hundred miles wide at its mouth. More than twenty superb rivers pour their waters into it, and the torrent that rushes from it into the ocean is borne along upon the surface in nearly a direct line, in spite of the currents that cross its course at right angles, its stream rendering the water perceptibly less salt than that of the ocean, at a distance of more than three hundred miles from the shores of America.

Although no river approaches in magnitude the gigantic Amazons, the river *Plata*, the fourth largest in the world in the extent of its river basin, and combining two important rivers, the Paraná and the Uruguay, is still worthy of more than passing notice. Like the Amazons, it receives at its affluence rivers which, in extent and magnitude, are of the first class. At Buenos Ayres, two hundred miles from its mouth, and along its whole course from that river to the sea, its breadth is never less than one hundred and seventy miles. It is subject to dreadful inundations, the Paraná, after the rains, rising every season and covering not less than 36,000 square miles of land. The water is exceedingly muddy, and can be traced in the Atlantic to a distance of two hundred miles from the coast of America.

The five next river systems of greatest importance in South America, the

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channels. Thus, the direct distance of the Rhine is shown by the table to be 360 miles, or 80 miles more than the Vistula; the development of its course is also 80 miles greater than the Vistula, but its windings are less, notwithstanding that the area drained by the former is much greater than that by the latter river. This table, and the deductions here expressed, as well as other tables of like nature which succeed, are given on the authority of Mr. Johnston's edition of Berghaus's *Physical Atlas*. The measurements are in geographical miles, of which sixty are reckoned to a degree of latitude. The geographical mile contains 6086 feet, and the British statute mile 5280 feet.

Tocantins, the Orinoco, the Paranahyba, the Francisco, and the Essequibo, do not together drain a greater area than the Plata and its tributaries. The Orinoco is, however, interesting for another reason than its extent, as it exhibits in the upper part of its course the very rare example of a natural canal, uniting it with another great river system. This canal, called the Casiquiare, connects the Rio Negro with the Orinoco. Its length is 120 miles direct distance, or 176 including the windings, and its width is 100 yards where it branches from the Orinoco; but on approaching its junction with the affluent of the Rio Negro, which forms the connecting link of the two systems, it amounts to nearly 600 yards. In addition to this curious network complicating two great and distinct river systems, the Orinoco in its detours follows such a direction that the course of the stream is apparently turned, and although the general direction of the stream is north-east, its mouth is found almost in the same meridian as some of its sources.

The largest of the North American river systems communicating directly with the Atlantic (that of *St. Lawrence*,) is much more remarkable for the great chain of lakes through which it passes than for any other phenomenon it presents. Of the 297,600 square miles which it drains, no less than 94,000 are covered with water, and the river runs through these lakes, bearing different names, and resembling rather a series of lake straits than any continuous stream. Of these lakes, the largest is Lake Superior, whose length is 400 miles, and mean depth 900 feet, and the smallest (with the exception of Lake St. Clair) is 100 miles in length and 500 feet deep. The Lake Superior is the westernmost of the whole chain, and is the largest body of fresh water in the world. It discharges its waters through the strait of St. Mary into Lake Huron, which receives also the waters of Lake Michigan, the next in magnitude to Lake Superior. The waters of Lake Huron (which is 240 miles long and 100 feet deep,) pass into Lake Erie, and thence, by the Niagara River, into Lake Ontario, forming in its course of 33½ miles the celebrated Falls of Niagara. The River St. Lawrence, which drains all these lakes, is not known by that name till after passing Montreal, but then, forming a broad estuary, it enters the Gulf of St. Lawrence, at Gaspé Point, by a mouth more than 100 miles in width. The other principal rivers of North America, belonging to the Atlantic group, offer nothing especially worthy of remark in this place.

The depression occupied by fresh water in the great lakes of the St. Lawrence system in North America is a phenomenon of considerable importance in the physical geography of this part of the globe. The principal lakes, Lake Superior, Lake Michigan, and Lake Huron, have a mean depth of nearly 1000 feet, and cover an area of 75,000 square miles; their surface is considerably less than 600 feet above the sea, and thus their bed has a mean depth of more than 400 feet below the level of the ocean. Lake Ontario, whose elevation above the sea is only 230 feet, but whose depth is 500 feet, presents to us another area of 6300 square miles, 270 feet below the sea level. This remarkable depression is paralleled by one other similar case, that which has been observed to the east of the Mediterranean, where the Dead Sea occupies a hollow more than 1000 feet below the sea level, and the whole interval between the Caspian Sea and the Lake of Aral is a depression from which the ocean has been recently drained.

In addition to the rivers already described as emptying themselves into the Atlantic, we have also several on the coast of Africa. There are some of them more important, and connected with larger river basins than the largest of those occurring in Europe, but they are much less completely known. The largest of them is the *Quorra*, or *Niger*, which, though not so extensive as the Nile, has, in all probability, a more extensive river basin. It is supposed to rise in about 9° N. latitude and 9½° W. longitude; but there are probably more sources than one of so extensive a stream. It flows along a course of as much as 2300 miles, and receives many very large affluents. The current of the river is moderate, and offers no impediments to navigation, and the river flows through more than one considerable lake. The *Senegal*, 850 miles in length, which drains two lakes and an extensive district, is the next largest river on this coast; and the *Gambia*, whose course is estimated at 600 miles, is also connected with a river basin of great extent. The *Gareep*, or *Orange River*, near the thirtieth parallel of S. latitude, has a long course through the table-lands of South Africa; and the *Zayre*, or *Congo River*, is a very important stream. Both the latter are, however, too little known, either with regard to the length of their course, or the extent of the country they drain, to enable us to offer tabular statements resembling those given above of the European and American streams.

78 *River Systems of Inland Seas opening into the Atlantic.*—Let us next consider those river systems which empty themselves into the great inland seas of the Atlantic Ocean. The general facts concerning them are given in the annexed table:—

NAME OF RIVER.	Area of the river basin in square miles.	Direct distance of river in miles.	Extent of development of river.	Extent of windings.
MEDITERRANEAN GROUP.				
Nile	520,200	1320	2240	920
Po	29,950	232	352	120
Rhone	28,160	248	560	352
Ebro	25,100	268	420	152
EUXINE GROUP.				
Danube	234,080	880	1496	616
Dnieper	169,680	548	1080	532
Don	168,420	408	960	552
Dniester	23,040	360	440	80
GROUP OF THE GULF OF MEXICO AND CARIBBEAN SEA.				
Mississippi-Missouri	982,400	1412	3560	2148
Rio del Norte	180,000	1220	1840	620
Magdalena	72,000	560	828	268
Motagua	7,040	196	260	64

Of the river systems of the Mediterranean group, that of the *Nile* is by far the most remarkable, from the great regularity and importance of the annual inundations in the lower part of its course, which fertilize Egypt. The absence of permanent streams as affluents for the last 1200 miles of its progress to the Mediterranean is also a remarkable fact. At its entrance into the Mediterranean, this noble river expands into a delta, which has been for a long period rapidly and steadily increasing. The sources of the Nile have been the objects of research to scientific travellers, and it would seem that one of its two principal head-streams rises in the table-land of Abyssinia, but the other is supposed to take its origin in the Mountains of the Moon. As it enters Egypt, the Nile runs in nine or ten cataracts or rapids, over a succession of terraces; but these cataracts of the principal stream are not so remarkable as those of the Tecazze, one of its tributaries.

The *Po*, draining a very considerable area of Northern Italy, is chiefly remarkable for its torrents and the delta at its mouth. It rises on the eastern side of Monte Viso, about 6000 feet above the sea, and is a rapid and irregular stream.

The *Rhone* rises in the Rhone glacier, 5500 feet above the sea. After passing through the Lake of Geneva, it enters France, and passes southwards into the Mediterranean. It is a very rapid stream, flowing at the rate of 120 feet per minute.

The *Danube* rises in the Black Forest at an elevation of 2850 feet above the sea, and running through the plains of Bavaria, it receives the two important rivers of the Isar and the Inn, proceeding from the Tyrolese Alps. For a considerable part of its course, it flows in a narrow valley, between two mountain ridges; but, after passing Vienna, it proceeds through open flat plains, except where in the celebrated defile of the iron gate, it crosses the eastern continuation of the great Alpine chain. It enters the Black Sea by no less than seven mouths, passing through an extensive swampy district, forming a delta.

The *Dnieper* and the *Don*, as well as the *Dwina* and the *Volga*, have their sources in low, flat districts, and present nothing remarkable in their course. The *Dniester* rises on one of the declivities of the Carpathians, and after running with a rapid current, and with a considerable body of water during the whole of its course, enters the Black Sea by a small delta.

The American rivers emptying themselves into the inland seas of the Atlantic are, like those which enter directly into that ocean, far more important in their magnitude and the extent of their drainage, than those of the Old World. The *Mississippi*, taken with its tributaries, forms the largest river system in North America, and one of the greatest in the world. The parent stream receives in its course two rivers, the Missouri and the Ohio; the first of which, coming in from the north-west, greatly surpasses the Mississippi itself, while the other is also a gigantic river, and the largest of its eastern affluents. The Missouri rises in two branches within a mile or two of the sources of the Columbia, and runs for 3000 miles before it joins the Mississippi; it is a very rapid river in the whole of its course, and itself receives several important affluents. The average velocity of its current may be estimated at 4½ miles per hour, but in times of freshets, is accelerated to 5½ miles per hour. The Mississippi has its source in two small lakes, about 1500 feet above the level of the sea, in latitude 47° 10′ north, and longitude 96° west. It runs through Lake Winnipeg, and flows with great velocity, forming several small falls. Before the waters of the Missouri mingle with it, it receives the St. Peter's river, the Wisconsin, the Illinois, and other streams, and its valley is bounded by high bluffs, intersected by deep ravines. After the junction of the Missouri, the course of the united stream becomes gentle, and the valley more open; and in its progress towards the Gulf of Mexico, it continues to receive very important rivers, of which the Arkansas and the Red River are those which have the longest course; the mouths of the Mississippi project far into the Gulf of Mexico, in a long and very remarkable delta, on which is built the city of New Orleans. Near its mouth, this vast river becomes a rapid, desolating torrent, loaded with mud. Its violent floods, produced by the melting of snow in high latitudes, sweep away whole forests, rendering the navigation very dangerous; and the trees matted together in masses many yards thick are floated down, and at length deposited over the delta and in the Gulf of Mexico, in an area of many hundred square miles.

The *Rio del Norte* is the largest of the Mexican rivers, but is too full of rapids to permit of any kind of navigation for a great part of its course. It rises in 40° north latitude, near the sources of the Arkansas, and of the Rio Colorado. Like many other of the great rivers of the world, it is subject to occasional freshets, but these do not extend to its lower course.

The *Magdalena* and the *Motagua* drain, the former, the north-western extremity of South America, the latter, the promontory of Yucatan. The Magdalena rises in the central chain of the Andes, and receives several streams in its course; the Motagua rises in the mountains near Guatimala, and flows into the Gulf of Honduras.

79 *The River Systems of the Arctic Ocean.*—The following table expresses, as far as they are known, the important facts connected with the Arctic system of rivers:—

NAMES OF RIVER SYSTEMS.	Extent of river basin in square miles.	Direct distance of rivers from source to mouth.	Extent of development of streams.	Extent of windings of streams.
ASIATIC RIVERS.				
Obi	924,800	1276	2320	1044
Yenesei	784,530	1228	2800	1572
Lena	594,400	1280	2400	1004
Kolyma	107,200	440	800	208
Dwina	106,400	380	864	484
Indigirka	86,400?	560?	908?	348
Olenek	76,800	600	1000	400
Anadir	63,360?	...	...	...
Petchora	48,800	360	600	240
Mesen	30,580	...	...	...
N. AMERICAN RIVERS.				
Mackenzie	441,600	964	2120	1156
Saskatchevan . . .	360,000	924	1664	740
Churchill	73,600	668?	848	180
Albany	52,800	380	560	180

Of the Asiatic rivers that empty themselves into the Arctic Ocean almost all are, as will be seen, of great magnitude and extent, but the nature of the country over which they pass, consisting for the most part of dreary plains, and the northern declivities of extensive table-land, conspires to render them almost useless for the support of vegetation, and therefore for the abode of man. The *Obi* and the *Irtish,* forming together the largest river of the Old Continent in the extent of its drainage, if not of its development, has so small an absolute elevation when it leaves the Altai mountains, from which it takes its rise, that for a distance of one thousand two hundred miles it has a fall of only four hundred feet, and although the bed of the river is very deep, the current is necessarily slow, and its banks are readily and constantly overflowed, forming immense marshes characterising a large part of Siberia.

The *Obi* is the most westerly of the three great rivers of Siberia, and the *Yenesei,* which drains the district to the east of the basin of the Obi, is little inferior in the magnitude of its basin, and has even a greater extent of development; some of its branches, which are numerous, have a very rapid course, but below Irkuktsh the current gradually decreases in rapidity. At its mouth, this river enlarges into an estuary twenty miles wide, and more than two hundred miles long. In its upper course, it passes through the Lake of Baikal, the largest and most remarkable of all the mountain lakes.

The *Lena,* the most easterly of the Siberian river systems, takes its rise from mountains a little to the west of the Lake of Baikal, and thence proceeds first in a north-easterly and then in a northerly direction to the sea. It is navigable for a considerable part of its course, receiving a number of important tributaries, and terminates in an extensive delta traversed by several arms of the river, three of which are navigable. Both it and the Yenesei are frozen near their mouths for nearly nine months of the year. The other rivers of Asia, emptying themselves into the Arctic Ocean, are of inferior extent and importance.

The *Mackenzie* is the largest river system which contributes its waters to the Arctic Ocean in the western hemisphere. It is formed by the union of several small streams, each designated by its own name, which rise on the eastern slopes of the Rocky Mountains, and after passing through Athabasca Lake, form Slave River, which again on leaving Great Slave Lake is called the Mackenzie.

The *Saskatchevan* rises with two branches in the Rocky Mountains, and these uniting at a distance of four hundred and fifty miles from their sources, run through Lake Winnipeg, and thence continue under the name of the Nelson River, into Hudson's Bay. The *Churchill* is another stream nearly parallel, passing through and draining several lakes, and at length terminating, like the Saskatchevan, in Hudson Bay.

80 River Systems of the Pacific.

Name of River.	Extent of river basin in square miles.	Direct distance of rivers.	Extent of development.	Extent of windings.
Asiatic Rivers.				
Amour	582,880	1200	2380	1160
Yang-tse-Kiang . .	547,800	1550	2880	1312
Hoang-Ho	537,400	1150	2280	1160
Tche-Kiang . . .	99,200	480	960	488
American Rivers.				
Columbia	194,400	576	1360	784
Colorado	169,200	512	800	288

The river systems of the Pacific Ocean are, as will be seen, of very great extent and importance in the drainage of Asia, but running through a territory so jealously guarded as China, very little is known of the country through which they pass. The *Hoang-Ho* and the *Yang-tse-Kiang* have their sources and their mouths in very close approximation, both rising in the extensive terraces on the eastern slope of the table-land of Central Asia, and emptying themselves into the sea between latitudes 32° and 35° N. These rivers are tidal to the extent of four hundred miles from their mouths, but they bring down with them a vast quantity of mud, which they deposit chiefly at the entrance of the Yellow Sea. They are separated during a great part of their course by a mountain ridge, which serves as a water-shed for a distance of several hundred miles.

The *Amour*, the third important river of Asia, empties itself into the Pacific by the Sea of Okhotsk. It rises in the Russian dominions, but runs for the greater part of its course through China; and there passes through a number of lakes, receiving many unknown and hitherto unnamed rivers, which take their rise from the edge of the great table-land of the Gobi. The *Tche-Kiang* system drains the tract of country south of the Yang-tse-Kiang, and its most important stream is best known under the name of the *Cambodia* river. This river, after traversing elevated plains, where it is navigable, rushes through the mountain barriers which border these plains, and crossing a wide valley, enters the Gulf of Siam by three principal arms.

The only important river of North America which contributes its waters to the Pacific Ocean is the *Columbia*, or *Oregon*, which rises in the most rugged steeps of the Rocky Mountains. It forms many rapids and cataracts, and is only navigable as far as Point Vancouver, a distance of about one hundred miles, to which point the tide reaches. The Colorado descends from the south side of the water-shed in latitude 41°, from the north side of which many of the tributaries of the Columbia take their rise, and after a considerable course enters the Gulf of California, traversing a country almost entirely unknown.

81 River Systems of the Indian Ocean.

Name of River.	Extent of river basin in square miles.	Direct distance from source to mouth.	Extent of development of streams.	Extent of windings of streams.
Ganges, including Bramahpootra .	432,480	824	1680	856
Irawady	331,200?	1100	2200	1028
Indus	312,000?	900?	1960?	864
Menam	216,000?	620?	940?	320
Euphrates	195,680	600	1492	892
Godavery	92,800	540	748	360
Kistna	81,600	440	688	228

Of these rivers it may be stated generally, that although the Ganges and Bramahpootra drain the largest area, the *Irawady*, which waters the Birman empire, and falls into the Bay of Bengal, and whose sources are in the same chain of mountains with those of the Bramahpootra, has both a longer direct distance and a greater extent of development. Its course, however, for the first eight hundred miles, is through countries not familiar to Europeans, although it is known to pass through a noble and rich plain, containing no less than four capital cities. From the city of Ava to its delta, which is very extensive, and presents fourteen principal channels, the river is more than four miles broad, but is encumbered with islands. It receives several important affluents.

The *Ganges* and *Bramahpootra* form a remarkable double system of rivers, whose sources are at great distances, but which converge to a common delta at the head of the Bay of Bengal. The Ganges commences at once in a very rapid stream, not less than forty yards across, proceeding from a huge cavern, in a perpendicular wall of ice. Thence it flows in a south-easterly direction through the plains of Bengal, receiving in its course a multitude of tributaries, of which no less than twelve are more considerable than the Rhine. The Bramahpootra takes its rise in the north of the Birman empire, probably from the eastern extremity of the Himalayan chain, and after winding for five hundred miles through Upper Assam, it enters the plains of Bengal and unites with the Ganges, about forty miles from the coast. The united delta of the two streams commences two hundred and twenty miles in a direct line from the Bay of Bengal, and extends for more than two hundred miles along the coast. The volume of water discharged by the Bramahpootra during the dry season is not less than 150,000 cubic feet per second, while that discharged by the Ganges, in the same time and under similar circumstances, is only 80,000. The quantity of mud brought down by the joint stream through the delta, in the wet season, is not less than 600,000 cubic feet (20,000 tons) per second, and the Sunderbunds, an innumerable multitude of river islands, forming a wilderness of jungle and forest trees, mark the extent to which such alluvial mud has been accessory in producing the present appearance of the mouths of these rivers.

The *Indus* and the *Sutlej* take their rise in the Snowy Mountains at the western extremity of the Himalayan chain, and both, fed by streams of melted snow from the northern side of this chain, flow westwards along the extensive valleys of Thibet. The two streams unite in the Punjab, and thence to the ocean the Indus does not receive a single accessory, but passes through a sterile desert. It empties itself into the ocean by a considerable delta, 60 miles in length, and occupying 120 miles of coast.

The *Euphrates* and *Tigris* form together the only important river system in Western Asia. The former rises in the heart of Armenia, and after running over a great extent of table-land, descends in rapids through the Taurus Mountains to the plains of Mesopotamia. The Tigris rises further to the east, and after piercing the same chain of mountains at Mosul, descends also to the plains of Mesopotamia. The two streams unite near the city of Bagdad, after which they run 150 miles, in one stream, to the Persian Gulf.

82 *Rivers not communicating with the Ocean.*—It now only remains to consider those rivers which, terminating in great inland seas of fresh water, and not proceeding thence to the ocean, form complete systems of drainage, entirely confined to the interior of extensive tracts of land. Examples of this kind occur in Africa and America to a small extent, but are nowhere so remarkable as in Central Asia, where nearly 1,200,000 square miles of country are drained by six river systems, three of which run into the Caspian, two into the Sea of Aral, and the sixth into a comparatively small lake, north of the great desert of Gobi. Another tract, nearly equal in extent to half this area, and continuous with it, appears to have a multitude of streams, which are either lost in small lakes after proceeding for a short distance, or disappear entirely in the great sandy deserts which they traverse.

Of these rivers, the *Volga* drains an area of nearly 400,000 square miles, and, with the exception of the Danube, has the largest volume of water of any river in Europe. The extent of its development amounts to 2400 miles, and its source (in latitude 57° N.) is nearly 1000 miles from the Caspian Sea, into which it discharges itself by no less than sixty-five mouths. The other important river system terminating in the Caspian Sea (the *Ural*) rises in the southern Ural chain, in latitude 55° N., at an elevation of 2132 feet above the level of the sea. The whole course of the river, including its windings, is probably not less than 900 miles. It forms, for a considerable part of its course, the boundary line of Europe, and, towards the south, is enclosed by steppes, and flows in a bottom varying from half-a-mile to two and a half miles in width. It enters the Caspian by a small delta, the islands of which are covered with salt swamps.

The principal feeders of the Sea of Aral are rivers not inferior to the largest in Europe; one of them, the ancient *Iaxartes*, is, in the area which it drains, of somewhat greater importance than the Danube, and its development is not less than 1200 miles. It flows from the east, through a country tolerably fertile, especially near its mouth, but that fertility is confined to a narrow band, and is bounded by deserts perfectly arid. The other river, the *Oxus* of the ancients, now called the *Amori*, enters from the south. It drains nearly 200,000 square miles of country, has an extent of development of 1400 miles, and the direct distance from its source to its mouth is more than 800 miles. The only other important river in the continental system of Central Asia is that which empties itself into the small lake of Lob, proceeding from the west eastwards. Little is known of this district, but the area drained is estimated at 177,120 square miles, and the development of the stream at 1080 miles.

There are not wanting continental systems of drainage in the New World, but they are comparatively small and unimportant. In North America, a small area of this kind occurs between the Gulf of California and the Rio del Norte; and the elevated lakes of the great plateau of the Andes, between latitude 13° and 31° S., receive a number of streams which do not afterwards proceed to the ocean. The Lake Titicaca, the largest in the South American continent, occupying an area of about 4600 square miles, and its surface 12,800 feet above the Pacific, is the recipient of the streams of a considerable district; these proceed by the River Desaguadero to a distance of about 180 miles into a small lake, and are there lost. The Catalena Lake, the Tor Lake, the Blanca Lake, and others in the same plateau, offer similar examples on a much smaller scale.

CHAPTER VI.

ATMOSPHERIC AND AQUEOUS ACTION.

§ 83. General nature of atmospheric and aqueous action. — 84. Changes produced by atmospheric action. — 85. Changes directly effected by alterations of temperature and exposure to cold. — 86. Glaciers and icebergs. — 87. Changes produced by the eroding action of moving water. — 88. The transporting and distributing action of moving water. — 89. Changes produced by water acting by the aid of substances held in solution. — 90. Indirect effects produced by water.

GENERAL Nature of Atmospheric and Aqueous Action.—The action of the air loaded with a larger or smaller quantity of water, and constantly changing in temperature, and the incessant motion of water in its various forms, whether as it passes under ground and emerges in springs, or moves along the surface, conveying particles of solid matter and depositing them in some new place, produce, on the whole, a very great amount of change upon the Earth's surface, greatly modifying the physical features of the globe, and influencing those conditions essential to the well-being of animal and vegetable life. A consideration, therefore, of what may thus be called *atmospheric and aqueous action* is an essential part of Physical Geography.

The mechanical action of water exhibits results in several different ways; for in one part of the world we find the sea with its restless waves beating against the shore, constantly removing a portion of the coast, and depositing it as mud in the immediate vicinity; while in other places, rivers carry along with them a quantity of earthy matter, manifested by their turbid appearance, and this earthy matter cannot fail to be deposited where the progress of the river is checked as it passes through nearly level plains, or when its stream meets the ocean, and its course onwards is thus completely terminated. The water carries mud along with it, however, only for a limited time, and strictly in consequence of its being in motion. Whenever, therefore, that motion becomes slower, a portion of the mud is deposited, and where it is stopped, the remainder must necessarily fall. Thus a river sometimes terminates in a triangular area of mud, called a *delta;* sometimes banks of mud, greatly impeding navigation, extend transversely across the mouth of the river, and are thence denominated bars; while sometimes there exist only a multitude of narrow channels, none of them deep enough to be navigable at the entrance. Where neither of these conditions occur, the mud is generally removed to a distance by powerful marine currents.

The action of water is not unfrequently dependent on meteorological changes; and amongst the most powerful agents of decay in cold climates or on mountain summits, must be ranked the expansion that takes place in water shortly before and during the act of congelation. In this way it is that although in temperate and cold climates the quantity of rain falling may not of itself be sufficiently great to produce, by simple mechanical abrasion, any considerable removal of the soil, yet the severity of the frost and the inequalities of the temperature may more than compensate for this diminished source of degradation. Hence, among aqueous changes we have to consider also the phenomena of *glaciers* and *icebergs,* by whose means vast quantities of broken fragments of rock, often of large dimensions, are first removed from the parent rock, and then conveyed by the assistance of marine currents to very considerable distances. We have also to take into consideration the action of running water, as well directly and periodically by rivers, as occasionally by unusual floods. We have, too, to consider the effect of the sea upon coast lines, and of tidal and marine currents under various circumstances, whether these take place in the open ocean or in inland seas which communicate with the ocean. Lastly, a certain amount of chemical change is produced by water, either by acids contained in it, or by the affinity of water and of the gases which it holds in solution for the various substances it encounters.

84 *Changes produced by Atmospheric Action.*—There is a constant tendency in all decomposed or disintegrated substances to be removed by the agency of rains and superficial waters to a lower level than they previously occupied, and finally to be transported into the sea. There is no rock, not even the hardest, that does not bear some marks of what has been termed weathering, or of the action of the atmosphere upon it. The amount of surface-change so produced is exceedingly variable, depending much on local causes. Thus, one rock may undergo complete disintegration in a certain situation, though composed of nearly the same materials as another rock of the same kind, of which the change has been comparatively trifling. When we contemplate the present surface of our continents and islands, we cannot but be struck with the great effects that have been produced upon them by the agents commonly known as *existing causes;* and among these effects, the weathering and degradation of land are very remarkable, attesting a lapse of time far beyond the usual calculations. The tors of Dartmoor, Devon, may be referred to as excellent examples of the weathering of a hard rock. These are composed of granite, which, as Dr. McCulloch has observed, are divided into masses of a cubical or prismatic shape. 'By degrees, surfaces which were in contact, become separated to a certain distance, which goes on to augment indefinitely. As the wearing continues to proceed more rapidly near the parts which are most external and therefore most exposed, the masses which were originally prismatic, acquire an irregular curvilinear boundary, and the stone assumes an appearance resembling the Cheese-wring (Cornwall). If the centre of gravity of the mass chances to be high, and far removed from the perpendicular of its fulcrum, the stone falls from its elevation, and becomes constantly rounder by the continuance of decomposition, till it assumes one of the spheroidal figures, which the granite boulders so often exhibit. A different disposition of that centre will cause it to preserve its position for a greater length of time, or, in favourable circumstances, may produce a logging stone.' The weathering of these tors is so exceedingly slow, that the life of man will scarcely permit him to observe a change; therefore the period requisite to produce their present appearance must have been very considerable. The surface of the whole country round these districts attests the same great lapse of time. Whatever may be the nature of the rock, it is disintegrated to considerable depths; porphyries, slates, compact sandstones, trap rocks,—all have suffered; but the valleys appear to have previously existed, and the general form of the land to have been much the same as it now is.

This destruction of the surface is common to most countries; and if the rock so weathered be limestone, there is, not unfrequently, a reconsolidation of the parts by means of calcareous matter deposited by the water that percolates through the fragments, and which dissolves a portion of them. At Nice, the fractured surface thus reunited is so hard, that, if it occur on a line of road, it must be blasted by gunpowder for removal. There are some fine examples of this reconsolidation upon the limestone hills of Jamaica; as, for example, near Rock Fort, and at the cliffs to the eastward of the Milk River's mouth.

The felspar contained in granite is often easily decomposed, and when this is effected, the surface frequently presents a quartzose gravel. D'Aubuisson mentions that in a hollow way, which had been only six years blasted through granite, the rock was entirely decomposed to the depth of three inches. He also states that the granite country of Auvergne, the Vivarrais, and the eastern Pyrenees, is frequently so much decomposed, that the traveller may imagine himself on large tracts of gravel.

Some trap-rocks, from the presence of the same mineral, are so liable to decomposition, that there is frequently much difficulty in obtaining a specimen. The depth to which some rocks of this nature are disintegrated in Jamaica is often very considerable.

This decomposition is attributed to the chemical, as well as mechanical action of the atmosphere. The oxygen of the atmosphere produces considerable alteration in rocks, more particularly observed in those containing iron, which are thus often reduced from a hard to a soft substance. With the slow and quiet changes effected by electricity on the surface, we are very imperfectly acquainted, but most of us have heard of destructive effects during a thunder-storm, of shivered rocks, and of fragments hurled from the heights into the valleys beneath. In these electrical discharges, the lightning often fuses the surface of rocks. Thus, De Saussure found a compound rock on Mont Blanc fused on the surface, white bubbles being on the felspar, and black bubbles on the hornblende. Similar observations have been made by other geologists in other parts of the world.

At Peninis Point, St. Mary's, Scilly Islands, there is a curious example of that decomposition of granite which antiquaries have termed rock-basins, and considered the work of the Druids. The Kettle and Pans, as these depressions are there named, occur in the large blocks of granite on the top of this promontory; they are generally three feet in diameter, and about two feet deep; they are mostly circular and concave, but there are others much indented at the sides. 'Some have perpendicular sides and flat bottoms, some are of an oval form, and others of no regular figure. Many of the blocks are six or seven yards high, eight or nine yards square, and several of them have four, five, six, or more of these cavities in them. A large rock, near the extremity of this group, has two basins of an immense size, besides several smaller ones. The upper and larger one appears to have been formed by the junction of three or more large basins. It is irregularly shaped, and about eighteen feet in circumference, and six feet deep. When the water in this basin has attained the height of three feet, it discharges itself by a lip into a lower basin, more regularly formed, the back of which is about five feet high, but which is incapable of containing more than a depth of two feet of water, owing to the declivity of the surface of the rock.' As a proof that similar decomposition sometimes takes place on the sides of a block, the author above cited mentions an oval cavity, six feet long, five wide, and nearly four feet deep, thus situated.

There is scarcely a substance, which, having been exposed to the action of the atmosphere for a considerable time, does not exhibit marks of weathering. It will even be observed on cliffs of sandstone, in which the cement varies in induration or otherwise, producing the most grotesque forms, which must be more or less familiar to the least observing. Variations in temperature much assist the chemical decomposing power of the air.*

85 *Changes directly effected by Alterations of Temperature and Exposure to Cold.*—We have just seen how rapidly disintegration of solid rocks may take place by atmospheric agency, and it may readily be imagined that when during frost, and by a sudden and rapid decrease of temperature, the water which had percolated into and filled narrow crevices, formed near the surface by ordinary exposure, was at first diminished, and afterwards almost instantaneously increased in volume, the rocks would split asunder with irresistible violence, and thus the effect be greatly increased. Various mechanical results are derived both directly and indirectly in this way, since

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* Delabeche's *Manual*, pp. 45—47.

not only are fragments split off from large masses of hard rock, but whole beds are altered in position, and way made for the subsequent removal of others of softer material, to which the running water of warmer seasons is now able to penetrate. On the shores of very cold seas, the cliffs are frequently formed more or less entirely of frozen mud, and the heats of summer generally tend to modify them, and even greatly reduce their dimensions, while on their reconstruction in the succeeding winter, way is made by the increase of crevices, both in number and extent, for the still further destruction of the whole mass.

All the changes and modifications produced by inequalities of temperature may, however, be regarded as destructive, effecting, even when the change is least marked, periodical removals of very large quantities of gravel and stones by the ordinary streams traversing a country, and in other cases tearing away enormous quantities of solid rock, and preparing them for further transport by rivers or ocean currents. It is only where the climate is more excessive than with us in England, that these modifications can be seen on a sufficiently large scale to attract general attention. In Russia, towards the mouth of the Dwina, there is an annual disturbance of the banks of that river, which is sufficiently extensive to be worthy of notice, for we find there long ridges or ledges of stones on the banks of the river about 30 feet above its summer level; the water, when at its height, penetrates into the chinks of thin beds of horizontal lime-stone, and in winter, becoming frozen and expanding, great disruptions of the rock occur, and stony fragments, often of large dimensions, are entangled in the ice. In the spring the fresh swollen stream inundates its banks, and so expands the water that the icy fragments are thrown up 18 or 20 feet above the level of the stream. In the course of five or six hours, the water will rise suddenly 14 or 15 feet, with the ice one compact mass upon it, and when the pressure increases, the ice is actually torn asunder, the crash that results resembling the roaring of artillery. What occurs on so considerable a scale in the river Dwina, and in other Russian streams, has been observed to a yet greater extent in Lapland, where granitic boulders, weighing several tons, have been seen suspended like birds' nests in the branches of pine trees, 40 feet above the summer level of the streams; and in Canada, on the St. Lawrence, as well as in the great rivers of Siberia, where the volume of the water is greatly more considerable, the changes of temperature more complete and more rapid, and where everything in nature is on a far grander scale, the consequences are still more marked. The packing of the ice in the St. Lawrence is a phenomenon of this kind, and when the broken ice is carried away by high tides in the spring, blocks of stone weighing many tons are frequently removed to a very considerable distance. The phenomenon of ground ice, however, or ice which, in spite of the expansion of water in freezing, remains entangled at the bottom of streams, proves that this action of water in the solid form is not confined to districts where the winter cold is excessive, but may extend even to such latitudes and climates as our own. Where, however, the circumstances are less unfavourable for the production ot such appearances as in some of the Siberian rivers, large stones are occasionally lifted from the river bed by the ice amongst them, and thus may be floated along for a great distance. Among the results of packed and ground ice may be mentioned the removal of gigantic blocks of stone weighing very many tons, sometimes shifted several feet in a season by the American rivers.

86 *Glaciers and Icebergs.*—When in very cold climates, or in mountain districts of great elevation, the rocks are exposed to frequent change of temperature near the freezing point of water, there must of necessity be a very considerable destruction produced, and this so much the more as the rocks are less covered with vegetation, or a coating of soil or gravel. This will be at once admitted, if we consider the constant absorption of water into crevices, the expansion of the water, and consequent widening of the crevices, and the

ultimate splitting off by this mechanical degradation. No one who has not himself had the opportunity of witnessing such phenomena, can do full justice to their enormous extent and influence, and the mere repeated observation of the forms of the rock will not itself give an idea, since the forms originally produced by the causes here referred to are perpetually repeated, although the actual surface of rock itself observed, and perhaps sketched at one visit, is closely imitated by that presented at another. Glaciers have been well described by Professor James Forbes as 'icy streams moving downwards, and continually supplying their own waste in the lower valleys, into which they intrude themselves like unwelcome guests.' They act chiefly as mechanical agents, transporting to a distance, and preparing for further travel, a vast multitude of blocks of stone, fragments of rock, gravel, and mud, and are amongst the most powerful agents employed by nature for this purpose. The quantity is often so great as almost entirely to conceal the mass of the ice under the prodigious load which, during a long descent, is accumulated upon it, while the dimensions of the transported masses are often gigantic, one having been seen by Professor J. Forbes on the glacier of Viesch, 100 feet long, and 40 or 50 feet high, and another being described containing nearly a quarter of a million of cubic feet of green slate, which has been conveyed by the glacier of Schwarzberg, although this glacier has since retreated at least half a mile, leaving the intervening space covered with smaller blocks.

The dimensions of glaciers are, however, required to give some idea of the amount of result they produce; their number also, if it were possible to enumerate it, might assist us in this conception. In Switzerland, these remarkable bodies vary in length from a few hundred yards to as much as twenty miles, and in width extend sometimes to as much as three miles. They may be seen in almost all the principal and a vast number of the secondary valleys, and everywhere produce the same results and exhibit similar appearances.

But Switzerland, although it offers very interesting examples of glaciers and glacier action, which may be visited with convenience and described at leisure and in detail by the observant traveller, is neither the only nor the most remarkable. On the south-western extremity of South America, we find 'a range of hills only from 3000 to 4000 feet in height, in the latitude of Cumberland, with every valley filled with streams of ice descending to the sea-coast. Almost every arm of the sea which penetrates to the interior higher chain, not only in Tierra del Fuego, but on the coast for 650 miles northwards, is terminated by tremendous and astonishing glaciers; and in Eyre's Sound, in the latitude of Paris, not only are there immense glaciers, but about fifty icebergs have been seen at one time floating outwards, one of which was at least 160 feet in total height, and these were all loaded with blocks of granite and other rocks of considerable size, different from the clay slate of the surrounding mountains.'*

On the coast of Greenland, at Spitzbergen, and in other places in the Arctic Ocean, where the temperature of the water is below the freezing point of fresh water, and also along the whole line of coast of the Antarctic Islands, there are constantly broken off vast fragments of ice which float away into warmer climates, conveyed by marine currents.

Three kinds of accumulation of ice are met with under these circumstances —the vast expanse of frozen surface-water detached from the shore, forming what are called ice-fields; smaller fragments of these, denominated ice-floes; and the lofty and massive portions, really broken off from glaciers, being the icebergs of the cold seas. Each contributes to illustrate the power of water as an agent of change on the Earth's crust, but the ice-fields and floes convey little or no detritus to a distance. The icebergs, on the contrary, whether numerous and of small extent, as they are successively broken

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* Darwin's *Journal of the Beagle*.

off in a sea warmer than the temperature of frozen fresh water; or allowed to swell into gigantic dimensions, as they creep along the sea-bottom, till the smaller specific gravity of this vast accumulation of ice, which is a little less dense than the sea water, causes a huge fragment to break off, and rise into an island—in either case abound with rocks and gravel.

The appearance and magnitude of such icebergs, in the Arctic Ocean, has been described as very variable, some having been seen aground in water three hundred fathoms deep, and others floating one hundred and twenty or one hundred and fifty feet above water, indicating a depth of nine hundred to one thousand feet, and a weight of not less than forty to fifty millions of tons. During the summer, round the shores of Cape Farewell, and throughout the year down Davis's Straits, these marvellous engines for distributing broken fragments of rock, course each other rapidly into the open ocean, and thence they proceed along the coast of America to latitudes as far south as that of Devonshire. By this time they have been most of them sufficiently broken and melted to lose their characteristic features, and gradually fade away from observation. From the Antarctic land similar drifts occur to still warmer latitudes, and very large floating bergs have been seen off the Cape of Good Hope, one of which is mentioned as having been two miles in circumference, and one hundred and fifty feet high, while others, if not of such great area, rose from two hundred and fifty to three hundred feet above the sea, and were therefore of great volume below.

The climate in high southern latitudes is, however, extremely severe compared with that of the northern hemisphere, since in Sandwich land, in latitude 59° S., corresponding in parallel to some parts of Scotland, the country was described by Captain Cook as covered many fathoms thick with everlasting snow, from the summits of the mountains down to the very brink of the sea-cliff, and this at the beginning of February, the hottest season of the year; and even in the island of Georgia, five degrees nearer the equator, or in the same parallel as Yorkshire, the line of perpetual snow descends to the level of the ocean. Still further towards the Antarctic Pole, as in the sixtieth parallel of south latitude, the temperature of the summer months ranges between 11° Fahrenheit and the freezing point of water, so that throughout the wide range extending from the two poles of the Earth halfway to the equator, there is a constant deposition of gravel and rock, removed and conveyed by the agency of ice. This although chiefly known in its effects in the northern hemisphere, must be far more considerable in reality towards the south, since the most southern glacier, which comes down to the sea in Europe, is nearly twelve hundred and fifty miles nearer the pole than those which are found on the west coast of South America; but evidence is not wanting of enormous results in that part of the world also, gigantic boulders occurring in the islands of Tierra del Fuego, on the high plains of Santa Cruz, and on the island of Chiloe, associated with a great unstratified formation of mud and sand, containing rounded and angular fragments of all sizes. In the vast ocean along which these bergs and islands of ice are conveyed, there must be distributed an enormous deposit of such materials, which are continually added to and occasionally reach the surface, as the undulations of the Earth's crust present new surfaces to the denuding and levelling power of the waves.

87 *Changes produced by the eroding Action of moving Water.*—Running water, whether the occasional result of rain recently fallen, and making its way to some continuous stream, or consisting of the stream of water itself in its progress to the ocean, exercises partly by simple attrition, and partly by the abrasion of sand carried along by it, a very considerable mechanical action. This action is twofold, either being of the nature of erosion, or the eating out a channel for the progress of the water, or else involving the deposit of mud and stones, tending to fill up the bed of a river, a lake, or an estuary. The waves of the sea beating upon a coast, whether produced by wind or by tidal

action, also produce a considerable amount of destruction, and marine currents eat out, from time to time, very large quantities of matter from the sides and bottoms of the channels through which they run, especially when these are soft, or when the current is rapid or steady. The eroding power of running water is sometimes seen in connexion with great floods in different parts of the world, as well as in ordinary river streams and marine currents, but the power is chiefly manifest in the beds of streams. A few facts, illustrating the nature of the results, will be interesting and instructive.

The rapidity with which even the smallest streams hollow out deep channels in soft and destructible soils, is well exemplified in volcanic countries, where the half-consolidated ashes present but slight resistance to the torrents which flow down the mountain sides. Sir C. Lyell mentions some interesting examples of this kind in his *Principles of Geology*, (seventh edition, page 200, *et seq.*) Amongst them he states, that after the eruption of Vesuvius in 1824, heavy rains produced streams of water, which, in three days, cut a new chasm through strata of tuff and ejected volcanic matter, to the depth of twenty-five feet. He also quotes the case of the Simeto, the largest of the Sicilian rivers, which, in the course of about two centuries, has eroded through lava a passage from fifty to several hundred feet wide, and in some places from forty to fifty feet deep. A remarkable instance of the force of water eating its way through a very considerable thickness of rock is mentioned also by Sir Thomas Dick Lauder, in his account of the great floods of Morayshire, in August, 1829. He states, that in one spot, the river Dorback, which before the floods swept round a conical-shaped hill, in a course of seven hundred and thirty yards, leaving a narrow neck of clayey gravel not more than a hundred feet in thickness, had nearly breached its way, but that, during the floods, the whole of the neck of land was likely to be destroyed. In order to save this, the river was assisted in its operations by human agency, and by one blow of a pick-axe the barrier, reduced to a dam of a foot thick, and just of a sufficient height to sustain the water, was burst at once. In the course of fifteen or sixteen hours, the channel was converted into a wide and complete river course, and within four-and-twenty hours the river had worked its way back to the depth of eight feet below the level of its old bed, now a dry channel. By the next February, the new channel was twenty feet below the level of the old river bed.

By far the most striking example, however, of this action of water, and of the progressive excavation of a deep valley in solid rock, is seen in the river and Falls of Niagara. The river flows over a flat table-land, in a depression of which Lake Erie is situated: where it issues from the lake it is nearly a mile wide, and is three hundred and thirty feet above the level of Lake Ontario, into which it empties itself at a distance of about thirty miles. For the first fifteen miles the surrounding country is almost on a level with its banks, and the river glides along with a clear and tranquil current, falling only fifteen feet in as many miles. Approaching the Rapids, it rushes over a rocky and uneven limestone bottom, and is then thrown down perpendicularly one hundred and sixty-five feet into a ravine, varying from two hundred to four hundred yards in width, and from two hundred to three hundred feet in depth. The river continues through this gorge in the table-land, for a distance of about seven miles, and the table-land then terminates in a long line of inland cliff facing towards Lake Ontario. On emerging from the gorge, the river proceeds, for the rest of its course, into Lake Ontario, through a flat country, nearly on a level with the waters of the lake. In this case, the structure of the rocks which form the table-land is such as to render it perfectly clear, that the falls have gradually receded from the escarpment, or cliff of the table-land, to their present position, and that they must, in the course of time, reach the upper lakes. When that is done, the water will have worn for itself a complete channel, not much unlike some of those water-worn ravines met with in other countries, the result of similar mechanical force acting at an earlier period of the Earth's history.

The mechanical action of water on exposed cliffs is sometimes very strikingly illustrated, as well directly on the rock exposed to the ceaseless dashing of the waves, as indirectly when rocks are undermined, and then fall by the action of gravity. Of the former, innumerable examples are to be found along almost every extended coast line in the world, while the undermining action, if not so widely traceable, is in many cases much more effectual.

The prevalence of strong westerly gales coming in from the Atlantic, and driving large waves upon the north-western coast of the British Islands, has broken the hard rocks of the Shetland Islands and those on the west coast of Scotland into deep caves and lofty pinnacles, so that almost every promontory ends in a cluster of rocks, the fragments of the former land. A sublime scene of this kind is described by Dr. Hibbert as occurring in the Shetland Islands, in what is called the Grind of the Navir, where a mural pile of porphyry, left as the last rampart against the inroads of the ocean, has been breached through in spite of its extreme hardness by the repeated assaults of the waves, and the breach is widened every winter, large stones being separated from its sides, and carried along to a distance of as much as 180 feet. The fantastic forms that are observed in the isolated granitic rocks in the whole of this district are due to the devastation thus produced, and the islands at first separated from the main land, and afterwards torn to pieces in this manner, must ultimately be carried away to form new beds at the bottom of the deep ocean.

On the east coast of Scotland, although more sheltered, the waves have produced great devastation; and in Yorkshire and Norfolk, the wearing of the coast has proceeded to a very considerable extent, even within such time as the position of towns and villages on the coast is recorded by historical documents.

Almost the whole coast of Yorkshire, from the mouth of the Tees to that of the Humber, is in a state of general dilapidation; and it is only at a few points that the grassy covering of the sloping talus marks a temporary relaxation of the erosive action of the sea. The chalk cliffs are worn into caves and needles in the projecting headland of Flamborough, and between that promontory and Spurn Point, the waste is extremely rapid, while Spurn Point itself threatens some day to become a mere island; in which case, the ocean entering the estuary of the Humber, must cause great mischief.

In old maps of Yorkshire, many spots are marked as the sites of towns and villages, which have long since disappeared. Several towns of note, upon the Humber, are now only recorded in history; and a port which was so considerable in 1332, that Edward Baliol and the confederate English Barons sailed thence to invade Scotland, and which in 1339 was selected by Henry the Fourth to land at, to effect the deposal of Richard the Second, is now represented by an extensive range of sands, dry at low water. In Norfolk, also, the decay of the cliffs is incessant and rapid. Between Weybourne and Sherringham it was computed, in 1805, that although the sea was gaining upon the cliffs, a period of seventy years would be required for the sea to reach the spot where an inn was built. In the year 1829, however, only a small garden was left between this building and the sea, seventeen yards having been swept away within the previous five years. At one point in the harbour of Sherringham, there was a depth of twenty feet in 1829, where forty-eight years previously there had been a cliff fifty feet high, with houses upon it. On the same coast, also, and near the same spot, several villages have disappeared, and large portions of parishes on the coast have been swallowed up. A little further to the south, a village has been partly swept away during the present century; and the town of Dunwich, which is now a small village, without the vestige of any better condition in former times, was once the most considerable port on this coast. Other parts of the east coast of England, and the mouth of the Thames, exhibit similar phenomena; the Goodwin Sands being, doubtless, a remnant of land once projecting beyond the chalk cliffs of the Kentish coast at Ramsgate, while the cliffs themselves, a little further to the south, are continually and rapidly being removed. Without dwelling farther on these accounts, which, however, are not only interesting but highly instructive as exemplifying important physical changes, we may conclude, so far as the British islands are concerned, by mentioning, and with some respect, the reports universal in the south-western extremity of our island, of a tract of land having extended beyond the present Land's End in Cornwall for a distance of nearly thirty miles to the Scilly Islands, though the intervening channel is now 300 feet deep. Accounts of the fragments of ancient pottery, and even portions of houses brought up by dredging, certainly lend some show of probability to this tradition, even if they cannot be regarded as altogether conclusive.

It may well be imagined, and is certainly the case, that our own coasts are not the only ones subject to great alteration from the beating of the waves, and the ceaseless inroads of the sea. The power of water to destroy a coast line, is even more distinctly exemplified where the coast is low and flat, as in the case of Holland; for there large tracts of land, and whole islands, have been removed at a single inundation; and in one case no less than seventy-two villages were overflowed in one season, (in 1421,) thirty-five of which were irretrievably lost and disappeared for ever, their place having been since permanently occupied by a sheet of water, called the Bies Bosch.

The bed of the Zuyder Zee, also, was in the time of Tacitus a portion of the mainland, only partly covered with fresh water, but the sea has entirely obliterated the former isthmus, which is now changed into a water passage, more than half the width of the straits of Dover, the breach being first completed about the year 1282, and afterwards widened. The important delta of the Rhine, although rapidly increasing in some places by the continued accumulation of solid matter, is thus greatly checked and interfered with by the ocean, which removes, in many cases, in a very short time, what has perhaps taken very many years to be deposited. Of all the United Provinces, Friesland and Groningen have suffered and continue to suffer most from these floods. Exposed to the full rage of the north, north-west, and west winds, the waters of the angry Atlantic and Polar seas rush towards these provinces, pour through the inlets of its barrier-reef—the Helder (Hels-deur—hell's door), the Vlie, and the more northern gates—heap themselves upon the inland Zuyder Zee, burst or overtop its dykes, and spread themselves over the country, sometimes to the very borders of Hanover. On these occasions thousands of men and cattle perish, the gates of the barriers become widened, and the dominion of the inland sea enlarged.

Thus, in 1230, a hundred thousand men perished, chiefly in Friesland. In 1277, the tract of land which now forms the Dollart, was swallowed up. In 1287, the Zuyder Zee was enlarged, and eighty thousand persons destroyed, with cattle innumerable. In 1395, the passage between Vlieland and the Texel and Wieringen became so widened, that large ships could sail to Amsterdam. In 1470, twenty thousand men were swallowed up, nearly all in Friesland; and in 1570, an equal number in that province alone. In the latter year, the water rose six feet above the dykes, covered even higher parts of the country with seven feet of water, and in Groningen destroyed nine thousand men and seventy thousand cattle. In 1686, it rose eight feet above the dykes, destroyed six hundred houses, dug the dead out of their graves, and converted Friesland into one wide sea. The seventh Christmas flood, in 1717, caused still wider damage in these northern provinces, burst through most of the dykes, laid the town of Groningen several feet under water, and destroyed twelve thousand men, six thousand horses, and eighty thousand sheep and cattle. And the struggle has not even yet ceased; for when the winds and floods conspire to increase the volume of water over the horizontal tract near the river's mouth, no human agency can prevent the destruction that must ensue.

In other parts of Europe, history records invasions of the sea not less extensive and scarcely less disastrous than those from which the Netherlands have so often suffered. Thus, in the eighth century, a tract of land was carried away on the north-west coast of France, near Mont St. Michel, and connecting that high land with the main coast; and in the Bay of Biscay the sea has in some places advanced so as to have destroyed a breadth of two miles of coast within a century.

At the head of the Adriatic there was a town anciently called Adria, and said to have been built on the sea shore by a leader of the ancient Etruscan race, about the time of the Trojan war. The present town, standing on the rubbish of two others, is now nearly sixteen miles from the nearest mouth of the river Tartarus, probably the oldest bed of the Po, and now terminating six miles within the farthest point of land projecting into the sea. Of late years, in making excavations at the depth of several feet below the present surface of the town, a former level was found, with numerous fragments of Etruscan and Roman pottery; and at a still greater depth, a second floor, where all the earthenware fragments proved to be Etruscan alone, and there were vestiges of a theatre. (?) In these facts, both the raising of the soil and progress of alluvial deposits are demonstrated, in waters but little disturbed by marine currents, and within a space of 3000 years.

Many other points on the coast of Europe would give abundant evidence of similar kind, but these are sufficient to prove how extensively the eroding power of water may assist to modify, not only a coast line, but the country to some distance inland.

On the shores of the two Americas, in various places, we have evidence of change to an enormous extent. The tidal waves and the marine currents have thus acted on the north-western coast, and the vast extent of sandy alluvial territory from the Gulf of Mexico to the summit of Long Island appears as if it were a late deposit, in part the debris of the Mexican and Caribbean portions of the continent, carried north, and thrown off when the Gulf Stream was formed. At the mouth of the Mississippi, the sea, of small depth along the whole coast, continues to recede before the delta of the river; and the Florida and Carolina shores, northward, form a series of lagoons on the ocean side. The stream rushes onwards in a north-east direction, and with a gradually decreasing velocity and temperature, (though both are still very perceptible off New York,) until it is finally neutralized at Nantucket, and the last particles of deposit suspended in it are precipitated to form the banks of Newfoundland. A continent torn asunder and washed away could alone furnish the immense alluvial surface and submarine banks here noticed. The rivers of the United States and Canada are not of a nature to have added more than feeble deltas, such as that of the Hudson at Sandyhook.

The shores of the Arctic Ocean between Asia and America and the intervening shallow sea offer proof of recent incursions of the sea in this part of the globe, and under circumstances where the change from other causes is likely to be rapid. There can be little doubt that the breach between the two continents, if not actually made, has been, at least, greatly widened by the action of currents setting southwards from the Polar Sea.

The mere action of the waves at the mouths of the great rivers both of Asia and America is unquestionably very considerable, but it belongs rather to the transporting and distributing action than the mere destructive force of this agent, and this will come under consideration in the next section.

It is sufficient now to remark, that all over the world there is a perpetual destruction of every exposed fragment of solid matter, and that, in this way, the modification of coast lines has been large, even within the narrow limits of human and recorded observations.

88 *The Transporting and Distributing Effects of Moving Water.*—The running waters of a river convey along with them the particles removed from their immediate banks, and the country over or near which they pass; and the quantity of matter thus carried along, and consequently the rapidity with which it may form such deposits, varies with the length of its course,

the volume of its waters, the nature of the country through which it flows, the velocity of its own upper current, the quantity of rain which falls in a given time in the regions from which its waters come, and the violence or rapidity of descent with which they fall from the heavens. Thus, a thousand gallons of the waters of the Oxus, when in flood, are said to hold in suspension two hundred and fifty pounds of mud (Burnes); of the Yellow Sea, fifty pounds (Staunton); of the Ganges, twenty-two pounds (Everest); of the river Wear, in flood, sixteen pounds (Johnston); of the Mississippi, six pounds (Riddell), and of the Rhine, at Bonn, two-thirds of a pound, according to Mr. Horner.

There is, no doubt, considerable uncertainty as to the absolute correctness of these numbers. They show, however, that the transporting power of rivers varies very much, and is sometimes much greater than we should have supposed or could anticipate. Even the small proportion of matter brought down by the Rhine is equal to 146,000 cubic feet of solid matter in twenty-four hours; so that, in two thousand years it would form a bed of rock three feet thick and thirty-six miles square. It is by this sediment that the low banks of the Rhine, where it is beyond the reach of the tide, have been gradually raised and numerous channels filled up, and by these means also the islands at its mouth have been in great part formed.

Such is the origin of alluvial soil, properly so called, and in this way are produced those rich sea-bordering clays, whose fertility is such as to induce men to risk disease in swampy climates, and expend unwearied toil in snatching them from the watery dominion, and defending them by huge dykes, which are too often destroyed by the subsequent incursions of the sea.

This transporting power of water is, of course, seen chiefly in those rivers which bear down to the sea a considerable volume of water from high mountain districts. Many of the European rivers possess the required conditions, and produce by their deposits very considerable additions to the land or the adjacent bed of the ocean, and amongst them the river Po may be mentioned as having within the last few centuries frequently changed its course, causing great devastation. This river has also produced great accessions of land in that portion of the Gulf of Trieste in which it and the Adige (to which its delta is now united) empty themselves. The rate of increase of this delta is now, and has been for some time, much more considerable than in the middle ages, the mountain torrents having become more turbid since the clearing away of the forests of the Alps, and the waters being so far confined by artificial embankments that they no longer spread over the plains, and leave there the great accumulations which they have obtained in their course, but convey everything at once to the sea. It is calculated that the mean rate of advance of the delta of the Po, between the years 1200 and 1600 was about twenty-five yards per annum, but that the mean annual gain from the latter period to the present time has been as much as seventy yards. The delta of the Rhone offers another interesting example of the rapid increase of land at the mouth of a river within the historic period, and at the same time the partial filling up of a great lake. The Rhone, entering the Lake of Geneva at its upper end, is turbid and discoloured, but at the town of Geneva, where it passes out of it, is beautifully clear and transparent. As there is no perceptible current in the lower part of the lake, it is manifest that the mud and sand brought in by the river must be deposited; and as a proof that this deposit chiefly takes place at the head of the lake, we find there an ancient town, built by the Romans, which was once situated at the water's edge, but now, after eight centuries, is more than a mile and a half inland. But the Rhone receives tributary streams, bearing with them a large quantity of sediment, after it has passed Geneva; and thus, besides partially filling up that lake, it carries with it into France, and at length leaves in the Mediterranean, a very large quantity of mud and silt. There are many documents which prove that the base of the delta has advanced into the Mediterranean very considerably within the last eighteen centuries.

Places which are described as islands a thousand years ago, and harbours constructed at that period, are now from three to six miles from the sea, and even a tower erected on the shore so lately as the year 1737, is already a mile remote from it.

The delta of the Rhine is, however, much more considerable than that of either of the rivers hitherto mentioned, and exhibits abundant proof of change by the increase of certain parts of it, and the constant shifting of the channels through which the river flows. The occasional encroachments of the sea, and the still further removal of the mud brought down by the river also tend to alter the delta. The present head of the delta of the Rhine is about eighty miles from the general coast line of that part of the continent, and forty miles from the Zuyder Zee. The whole of Holland, without exception, is on the delta of this river, and the thickness of the mud accumulated is very considerable, although the nature of the deposit varies a little at different depths. Many islands have been destroyed, new straits and estuaries formed, and the coast line greatly altered by the sea within a comparatively short period near this important stream. The Danube and the Nile afford other examples of the same kind and on even a larger scale. The delta of the former river occupies an immense area, its two extreme channels being distant from each other eighty miles; but the case of the Nile is still more remarkable, its delta occupying, with the lagoons, an area of 20,000 square miles, within which are contained all the cultivated lands of Egypt. The form of this delta, as described by the ancients, is, however, exceedingly different in almost every respect from that which is now to be observed, and the magnitude is also very different. It has always consisted of a perfectly level plain, nowhere offering the smallest natural elevation, with the exception of a few sand dunes near the sea. The soil of the delta is everywhere formed by the alluvial matter brought down by the river, and this each year is covered by a fresh coat when the annual inundation spreads over the land.

But considerable as are the deltas of these European and African rivers, those of Asia and America are still more remarkable. The Ganges and the Bramahpootra have been already mentioned as entering the Bay of Bengal through a considerable tract of country entirely formed by the mud which these rivers have brought down from the mountain country and the plains which they drain. The delta of the former of the two rivers, which is now continuous with that of the latter, extends for 200 miles between the two principal arms of the Ganges, which bound it on each side. When the river is low, the tide extends even to the head of the delta, a distance of 220 miles, in a direct line from the coast, but when swollen by the tropical rains the velocity of the stream is sufficiently great to counteract the tidal current, so that the movements of the ocean are altogether subordinate to the force of the river. We have thus during different periods of the year two distinct operations produced by the action of water. During the flood season, the delta increases greatly in height and area, while during the rest of the year the ocean scours out the channels and removes very extensive alluvial plains. The amount of deposits necessarily depends on the quantity of mud held in suspension by the waters of the river, and as in almost all respects the Ganges is favourably situated for receiving and conveying to the ocean very large quantities of transported material, the rate of increase might be expected to be, and is, more considerable than in almost any other river. In point of fact, the average quantity of solid matter suspended in the water near the mouth of the river during the rainy season has been estimated by Mr. Everest to amount to $\frac{1}{428}$th part by weight of the water discharged. As the number of cubic feet of water discharged per second in the four rainy months may be estimated at half a million, it is easily shown by calculation that during the hundred and twenty-two days of rain, upwards of six thousand millions of cubic feet of mud must proceed down the river and be deposited in or near the delta. It is difficult to form any notion of the true meaning of numbers so large; but in order to assist the imagination, Sir C. Lyell has estimated that this quantity of solid matter is equal in weight to fifty-six and a half times the great pyramid of Egypt if that were a solid mass of granite.* It will also assist the reader to form an idea of this quantity to know that if a fleet of eighty Indiamen, each freighted with fourteen hundred tons weight of mud, were to sail down the river every hour of every day and night for the four months continuously, they would only transport from the higher country to the sea a mass of matter equivalent to that actually conveyed by the waters of the river. It is probable that the waters of the Bramahpootra convey annually as much solid matter to the sea as those of the Ganges, but the delta is not so considerable.

The river Mississippi also exhibits on a very large scale examples of the power of running water, both in filling up lakes and forming an extensive Delta. The superficial dimensions of the true delta of this gigantic river amount to as much as about 14,000 square miles, and the quantity of solid matter annually brought down by the river is nearly four thousand millions of cubic feet. As the mean depth of the deposit of mud and sand is upwards of 500 feet, it would thus appear that the whole area might have been formed as we see it now in a period of about 67,000 years, but the delta is itself only a portion of the great alluvial plain in which it is placed, and this plain has also been formed by the sediments of the river, and must have required at the same rate more than 33,000 years for its accumulation. Sir C. Lyell has well observed, in reference to this subject, that the whole period during which the Mississippi has been transporting its earthy burden to the ocean, though, perhaps, far exceeding 100,000 years, must be insignificant in a geological point of view, since the bluffs or cliffs bounding the great valley, and therefore older in date, and which are from 50 to 200 feet in perpendicular height, consist in great part of loam containing land, fluviatile and lacustrine shells, of species still inhabiting the same country.

The Mississippi is remarkable not only for its delta, but also because in various parts of its long course, some considerable lakes are now in process of formation, while others are being rapidly drained. The most considerable example of the former phenomenon occurs in Louisiana, in the basin of the Red River, where Lake Bistineau, as well as several others, have been formed by the gradual elevation of the bed of the river, in which the alluvial accumulations have been so great as to raise its channel, and cause its waters during the flood season to flow up the mouths of many tributaries, and convert parts of their courses into lakes. Sometimes these lakes are merely reservoirs, alternately emptied and filled in the dry and flood seasons; but in other cases, some natural or artificial obstacle prevents the efflux of the water, and produces a permanent lake. The Lake Bistineau, already mentioned, is of this kind: it is upwards of thirty miles long, and has a medium depth of fifteen to twenty feet. Numerous cypress trees are seen even in the deepest parts, still standing erect under water, although they are now dead, and the tops of most of them are broken by the wind. It is indeed possible that subterranean movements may have assisted in the production of some of these lakes, but the causes mentioned appear to be the most important.

89 *Changes produced by Water acting by the Aid of Substances held in Solution.*—Springs of water charged with calcareous or siliceous matter may, under some circumstances, produce an effect by no means inconsiderable, especially in volcanic districts. Although, therefore, the total amount of the results thus produced is not very great, their local extent renders them worthy of a passing notice.

Auvergne, in central France, offers an example of calcareous incrustations and deposits from springs, which have formed an elevated mound of white

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* The base of this pyramid covers eleven acres of ground, and its perpendicular height is about 500 feet.

limestone, two hundred and forty feet long, and at its termination sixteen feet high, and twelve wide. Tuscany presents other examples of the same kind; so that in some places of considerable extent the ground is completely coated with deposited rock of this kind, and sounds hollow beneath the feet. The river Elsa, a tributary of the Arno, flows through a valley several hundred feet deep, of which the whole containing district is of the same recently formed rock.

At the baths of San Vignone and San Filippo, also in Tuscany, springs issue of warm temperature, containing salts of lime and magnesia; and deposits of calcareous matter of very great thickness, occur in the immediate vicinity: one stratum of many layers, used as building stone, having a thickness of fifteen feet, and a portion of the main deposit descending in a different direction to the rest, being more than two hundred and fifty feet long, and sometimes two hundred feet deep. It is then cut off abruptly by a small river, so that a much larger quantity of calcareous matter than that deposited has evidently been removed to the sea.

Other streams, as in the Azores and the volcanic island of Iceland, consisting of greatly heated water, contain, held in solution in the water, a very large quantity of silica, and, indeed, more or less of this mineral is probably present wherever there is any quantity of the salts of soda in solution.

The silica in water is sometimes, but rarely, deposited, like the calcareous matter, in layers, producing chalcedonic masses, which often resemble stalactitic and stalagmitic incrustations, but more frequently it assists in cementing various materials aggregated together, and thus forming stone from loose sand and the conglomerates and breccias of various districts.

90 *Indirect Effects produced by Water.*—In addition to these examples of the direct action of moving water, in conveying to a distance fragments broken off from cliffs, or displaced by the more gentle action of rivers, it is worth while to notice, before concluding this chapter, some less direct results of aqueous action which assist greatly in producing change. Land-slips in which considerable tracts fall away from a coast by the undermining action of water are phenomena of this kind, but they have reference rather to the structure of the Earth than to the actual mechanical force of waves and currents. In the year 1839, an extraordinary occurrence of the kind took place on the coast of Dorsetshire, between Lyme-Regis and Axmouth. The cliffs here consisting of chalk, reposing first on sandstone, and then on loose sand, have for their ultimate basis extensive beds of clay, shelving towards the sea. Numerous springs of water, the drainage of the surrounding country for a considerable distance inland, came out along the shore, and in the course of an exceedingly wet season, so much of the sand had been removed, that a considerable portion of the cliff was partly undermined, and on the morning of the 24th of December, in the year mentioned, a crashing noise was heard, succeeded by numerous fissures opening in the ground, until a deep ravine was formed, extending nearly three-quarters of a mile in length, with a depth of from a hundred to one hundred and fifty feet, and a breadth exceeding two hundred and forty feet; and, after a short time, an elevated ridge was formed more than a mile in length, and forty feet high, by the pressure of the descending rocks producing an extended reef in front of the present range of cliffs.

PART II.

THE STRUCTURE OF THE EARTH.

CHAPTER VII.

THE CONDITION OF THE INTERIOR OF THE EARTH AND THE REACTION OF THE INTERIOR ON THE EXTERNAL SURFACE.

§ 91. Means of obtaining a knowledge of the Earth's interior. — 92. Internal temperature of the Earth as determined by deep sinkings. — 93. Thermal springs. — 94. Volcanoes. — 95. Volcanic products. — 96. Distribution of volcanoes. — 97. Subterranean connexion of distant volcanoes. — 98. Connexion of volcanoes with earthquake action. — 99. Nature of earthquake movements. — 100. Frequent repetition and wide range of earthquake action. — 101. Permanent change of level accompanying earthquake action. — 102. Origin of earthquakes. — 103. Partial, but permanent, elevation at a distance from volcanoes. — 104. Depression over large areas.

MEANS of obtaining a Knowledge of the Interior of the Earth.—We have now considered in succession various phenomena connected with the Earth's surface, including the atmospheric and watery oceans reposing on the land, and also some of the mechanical results of the mutual action of the different forms of matter presented to us: we have next to describe the condition of the Earth's crust, or, in other words, to give an account of the actual solid substance of so much of the superficial coating of our globe, as it is possible for us to become acquainted with, either by direct observation or fair induction. The observations required are of various kinds, but cannot, under any circumstances, have reference to such a depth from the mean level of the surface, as will justify us in assuming with certainty the condition of the great mass of the interior of the Earth. Since, however, we have in nature many opportunities presented to us for determining the Earth's structure for a depth of at least several miles, owing to the fact that various portions have been thrust up from beneath by subterranean force; and that by natural crevices and fissures in various rocks and by artificial sinkings to obtain mineral produce, by regarding the structure of cliffs, both marine and inland, and by marking the nature of soils and their relations with the underlying rocks, we have many means of determining facts as to the materials of this crust and their mode of arrangement, it becomes a very essential part of Physical Geography to consider the state of the interior of the globe in various parts of the Earth, whenever observation will allow us to do so.

92 *Internal Temperature of the Earth as determined by Deep Sinkings.*—Whenever there has been an opportunity by sinkings made to any considerable depth below the Earth's surface to determine the temperature, it has been found that while at the surface, the mean annual temperature is more or less widely departed from in different parts of the year, according to local circumstances, this variation becomes less and less considerable as we descend; so that after a time we arrive at a certain point, to which the heat of summer, and the cold of winter, do not in any degree penetrate, but the thermometer shows throughout the year the same point—namely, the mean annual temperature at the surface. This point is at different depths in various parts of the Earth. In the torrid zone, under the equator, it is often

not more than a foot from the surface, in our own climate it is from sixty to sixty-five feet; and thus connecting such points beneath the external surface of the Earth, there is also an imaginary surface or stratum of invariable temperature, above which the seasonal changes are felt, but below which any observations that can be made must be supposed to have reference to the absolute temperature of the Earth.

It is not, however, necessarily the case that we can, from such observations, judge of the true condition of the Earth at great depths. The vast period of time during which the sun has been shining upon our globe, and communicating, in whatever way, heat as well as light; the amount of chemical change unquestionably going on beneath the surface, excited by terrestrial magnetism; and other causes, of whose mode of action we know indeed but little, but which are not the less certain and important, and which certainly produce great molecular change:—these may have been sufficient to produce a certain amount of heat, which, however slowly it is propagated through so bad a conductor as the materials of the Earth's crust, may in the lapse of time have given to the mass, at least to some considerable distance in depth, an absolute temperature much higher than even the mean annual temperature of the tropics. Bearing in mind this possibility, it may be mentioned, as the general impression and belief amongst those who have investigated most carefully the facts of the case, that the internal heat below the stratum of invariable temperature, may really be considered as a guide to the condition of the interior of the Earth; and when, therefore, we find, as we do, that in descending below this stratum, the temperature gradually rises, increasing pretty regularly for some distance at the rate of 1° Fah. for every forty-five feet of depth, there appears reason to suppose that at a comparatively small distance from the surface of the Earth towards its centre, there must be heat sufficiently great to reduce to a state of fusion even the most refractory of those masses which present themselves as rocks at less considerable temperature. Assuming that the increase continues regularly in the same ratio, we should reach the boiling point of water at about two miles depth, and at a depth of twenty-four miles we should arrive at the melting point of iron. Now, when we consider that the Earth's diameter is nearly eight thousand miles, we shall see how little it is possible to judge of the state of the interior, even with the assistance of the conclusions drawn from such observations as have been mentioned; but it should be observed that the experiments upon which these conclusions depend are very numerous, and have been very carefully made, and depend not merely on such deep sinkings as are connected with mines, but also on Artesian borings, in which the temperature of the water is found to be constant, and seems entirely derived from passing through the strata of the Earth.

The experiments alluded to, do not exhibit a result absolutely uniform; the increase of temperature is by no means the same for the same depth, even in mines in the same district; and while the mean rate of increase in six of the deepest coal mines in Durham and Northumberland is one degree Fah. for a descent of forty-four English feet, it appears to be only one degree for every sixty-five feet in some of the deep mines of Saxony; while in others, in the same district, it was necessary to descend thrice as far for the same amount of increase. In Cornwall, careful observations, continued for eighteen months in the Dolcoath mine, at the depth of 1380 feet, gave as the rate of increase one degree for each seventy-five feet; but in other mines, in the same district, very different results are obtained.* On the whole, there is no doubt, from the irregularities manifested in every extensive series of observations, both in the absolute and relative increase of the internal heat of the

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* In Ireland, observations made in the Knockmahon copper mines, in the county of Waterford, the increase, after making every allowance for the vicinity of the sea, was found in 774 feet, to be only at the rate of one degree for nearly 82 feet. It was found that the temperature was slowly diminishing, and remained more considerable in the lode than in the containing rock.—*Report of British Association for* 1844, p. 221.

Earth at considerable depths, that up to the present time, no general law can be considered as applicable, and therefore no general conclusion can be safely arrived at. Even the fact of the diminishing rate of increase for equal increments of depth, although apparently true of depths not exceeding 150 fathoms, has been called in question by Mr. Henwood, whose observations, extending over a considerable number of very deep mines, appear to have established the fact, that after 150 fathoms the ratio alters, that depth appearing, in Cornwall, to present a limit to the continued increase of temperature in the same ratio. It also appears to be the case in the mining district in question, that this depth in the mines hitherto worked (and in which, therefore, such observations were made,) is also the limit of the principal masses of metalliferous deposits, and thus arises a possibility of this minimum of ratio being, after all, nothing more than a local peculiarity, owing to the mode of distribution of metals and metalliferous ores.

93 *Thermal Springs.*—The temperature of water obtained by artificial boring has nowhere amounted to more than 82° Fah., and in this case, at (Grenelle, near Paris,) the depth being about 1800 feet, the rate of increase below the surface of invariable temperature showed 1° for 60 English feet; but very much higher temperatures than this occur in the water of springs in various parts of the Earth. In England we find, at Bath, water rising through crevices in stratified rock at the temperature of 66° Fah. In Germany, the springs at Töplitz, Ems, Aix-la-Chapelle, Wiesbaden, Carlsbad, and Borset, (Lower Rhine province,) exhibit temperatures of 71°, 81°, 85½°, 108°, 117°, and 121½° respectively; the mean annual temperature at the surface in these districts being not far from 50°. At Baden-Baden, where the mean temperature is somewhat higher, the hottest spring shows a temperature of 96½°, and at Buda, near Presburg, in Hungary, there are springs of 93½° and 95¾° respectively. In the north of France, at Plombieres, there are springs whose temperature is 95¾°, and others near Chaumont of 80°. Further south, near Aurillac, there is a spring showing 118°; and at Neris, in the department of the Allier, one of 89½°. At Thuez, in the Pyrenees, water rises at the temperature of 111½°, and at Ax, near Tarascon, 108°. In Italy, in Piedmont, there is a spring showing 107°, and at Abano, near Padua, one of 121°. The baths of Nero have a temperature of 121°; at Coquinas, in Sardinia, the water attains 98°; and in Ischia there are springs whose highest temperature is 94½°. At the base of Mount Olympus, there is a group of thermal springs, the water of one of which raises the thermometer to 113°; while in Iceland, and in other places more directly adjacent volcanic disturbances, it is not unusual to find permanent springs of nearly pure water within a few degrees of the boiling point, and even in some cases above it. These springs, for the most part, have been flowing without change for a very long period, and occasionally afford good evidence that during several centuries they have remained permanently at the same temperature, the quantity of the water also proceeding from them with undeviating regularity. This quantity varies of course exceedingly in different springs, amounting sometimes to several hundred thousand cubic feet per day, and in others being much more limited. In many, the water is charged with a sensible proportion of saline ingredients, but in others it is perfectly pure. The fact of there being so many localities, in different and distant districts, pouring water from the bowels of the Earth having a temperature higher than the mean temperature of the atmosphere at the surface, is sufficient proof that there are very widely acting causes of a uniform nature far beneath the surface, and that these causes may tend to elevate the temperature at those more considerable depths to which man has not been able to penetrate.

It would be improper to omit in this account of the phenomena of thermal springs some notice of these magnificent fountains of boiling water to which the name of Geysers is applied, and which burst from funnel-shaped hollows in the lava plains near Mount Hecla, in Iceland. The great eruptions of this fountain seem to take place once in about twenty-four or thirty hours, but not with any regularity, the discharge being greatly affected by the eruptions of the neighbouring volcano, and the periods having frequently undergone great change. The eruption is described by Krug von Nidda as being preceded by a hollow rumbling sound, and a number of explosions, accompanied by a violent quivering motion in the ground. The author then states, that 'having been driven from the spot by this movement, he turned at a little distance, and beheld a thick pillar of vapour shooting like an arrow to the clouds, and surrounding a body of water, which rose with a fluctuating motion to the height of eighty or ninety feet, some portions of the fluid rising even above this, or streaming in arches from the cloud. Sometimes the steam divided, and exhibited the aqueous column shooting upwards in innumerable rays, spreading out at the top like a lofty pine, and descending in fine rain; at other times it closed in thicker darkness round the centre, veiling it from the eyes of the spectator. The eruption continued about ten minutes, when the water sank down into the pipe, and the whole was again in repose, the basin being completely empty, and the water far down in the pipe, and slowly ascending.' *

With regard to this subject of thermal springs, it is right, however, to make the same qualified remark as that offered at the close of the last section. In some places, the temperature of natural springs proceeding from considerable depths beneath the surface is not greater than the temperature of the surface, and in some instances is even lower. If we take the case of all those springs which may properly be termed thermal, that is, of which the water is somewhat warmer than the mean annual temperature of the air at the surface, we shall find that whilst many of them occur in districts which now present no indications of what are generally considered volcanic phenomena, on the other hand, there are scarcely any, if any, volcanic districts in which hot springs do not abound. Many of those districts, however, in which no volcanoes now appear are really and very distinctly marked by volcanic phenomena of ancient date, while the rest are almost all of them either at the foot, or in the midst of some partially elevated tracts or mountain chains. Such mountains we shall have to prove in a future chapter are connected very directly with igneous action, often on a much larger scale than is manifested in volcanoes themselves. Even where this is not the case, there are still some geological phenomena indicating, although more distantly, such fractures and dislocations as result from igneous action.

94 *Volcanoes.*—The connecting link between thermal springs and eruptions of mixed gaseous fluid and solid substances, from conical elevations called volcanoes, is considered by Humboldt to be traceable in the so-called *Salses*, or mud volcanoes, of which examples occur in various districts, and which combine a number of phenomena bearing upon the general question of the condition of the Earth at some distance below its surface. One of these mud volcanoes was first formed about twenty years ago on the shores of the Caspian Sea, near Baku, and in this instance flames blazed up to an extraordinary height for the space of three hours, and during the following twenty hours rose about three feet above the crater, from which mud was ejected, while enormous fragments of rock were hurled to a great distance around. But such a condition of activity is rarely seen in mud volcanoes, which more usually consist of small mounds from eight or ten to thirty feet high, having small basins on their summits, from which mud (generally cold) and gaseous eruptions, accompanied by noise, are more or less constantly issuing. For fifteen centuries, a Sicilian Salse, near Girgenti, has been in this inferior stage of activity; and many others of the same kind are described in other parts of the world; the temperature of the mud, and of the gases erupted, being often higher than the mean annual temperature of the district.

True volcanoes are phenomena very different in kind, as well as enor-

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* Krug von Nidda, Karsten's *Archiv.*, ix. 247. See the account of Iceland, Greenland, and the Faro Islands, in the *Edinburgh Cabinet Library*, 1840, p. 59.

mously greater in extent, and we may consider that they involve in every case a more or less continuous but permanent communication between the interior of the Earth, or some large cavity, and the atmosphere, and although such communication may be interrupted for months, years, or even centuries, it may afterwards recur with all its original energy. When traces of the first eruption exist, the volcano generally appears to have risen from the middle of a more extended area of circular or elongated form, elevated so as to form a cup-shaped cavity or crater, and an isolated cone presents itself in the centre of this, having at its summit a similar small hollow, also called by the name of crater. As offering a tolerably complete exhibition of volcanic agency, there are, perhaps, no more interesting and instructive examples than those of Santorin in the Greek Archipelago, and Kilauea in the Hawaiian (Owyhee) or Sandwich group of islands. The former, thirty-six miles in circumference, exhibits the form of a large and broken submarine crateriform mountain, in parts of which volcanic activity may be constantly observed. The latter presents the only well-marked instance on our globe of a large deep pit open to the sky, having clear bluff walls for the greater part of its circuit, with an inner ledge or plain raised above the bottom, which consists of solid lavas, with some cones of considerable size, and some pools of lava in a state of constant and active ebullition.

A more detailed account of both these indications of volcanic activity would prove very useful, in enabling the student to comprehend the sequence of volcanic phenomena, but the limits to which we are confined will not allow of this digression, and we can only quote the following notice of the Volcano (as it is called) of Kilauea, on the southern declivity of the table-land of Hawaii, whose elevation is eight thousand feet above the sea, and which occupies the centre of the island, measuring fifty miles in length, from south to north, and forty miles in its broadest part. Near the edges of the table-land are three volcanoes, the highest of which, Mouna Kea, is 13,587 feet above the sea, and is now extinct. It is near the eastern declivity, and is opposed by Mouna Roa, which is near the south-west corner, and is 13,175 feet high, and not in a state of very recent activity, but exhibiting an ancient crater not less than twenty-four miles round. On the western edge of the table-land is Mouna Huararaï, whose height is estimated at 10,000 feet, and which is now active. On the southern slope is situated Kilauea, which is a depression below the general surface of the slope of somewhat irregular shape, with almost perpendicular sides. The elevation of the slope, where this vast pit occurs, is 3873 feet above the sea. The steep descent to the crater is interrupted by two narrow plains or ledges, one of which is 715 feet below the upper surface, and the other about 100 feet. The surface of the volcanic lakes is forty-three feet below the last-mentioned ledge. The crater contains two lakes, the smaller of which is almost circular and nearly 1000 feet across—the larger is more than 3000 feet long, and in one place 2000 feet wide. These lakes are vast caldrons of lava, in a state of furious ebullition, sometimes spouting up to the height of twenty and even seventy feet. The fiery waves run with a steady current at the rate of nearly three miles and a quarter per hour to the south, enter a wide abyss, and ultimately pour into the sea. This remarkable volcano has, from time immemorial, been prodigiously active, though it has not, within the memory of living men, been known to overflow except in 1787, when a dreadful eruption took place, which lasted seven days.

There are few other instances of this kind on the globe, in an active state. On the surface of the moon there are strictly analogous appearances, represented on a much larger scale, some pit craters having been described, which measure from 5 to 150 miles in diameter, and 5000 to 24,000 feet in depth.

While this simmering and boiling of molten rock, and the formation of a crater, is carried on in the large caldron-like pits just described, other results of volcanic action are illustrated by the formation of conical hills, either in the blister-like swelling of a considerable area, or the rapid accumulation or eruption of a single mountain. Thus, we find recorded by Humboldt, a very striking instance of such subterranean movement, in the production of the district and mountain of Jorullo, in the plains of Malpais, which form part of the plateaux of Mexico. These plains are a hundred miles distant from the sea-coast, and 2500 feet high, and are bounded by basaltic mountains. No active volcano is near, and the whole occurrence presents a view of one of the most extraordinary physical revolutions recorded in the history of our planet; for it is rare, indeed, that man has an opportunity of seeing so extensive a change commenced and concluded within a period of time so short as that of the ordinary duration of human existence.

What took place at Jorullo has occurred in former times on an infinitely grander scale, not only in those districts where groups of volcanoes now pour forth fire and melted rock, but in a vast number of other places where this fire has long since spent itself. The phenomena of volcanoes must be considered, then, in reference to those which are extinct, as well as those now active; and the distribution of volcanoes becomes of interest, not only with reference to the present land, but to the form of the Earth's surface at all antecedent periods. We have already mentioned, that volcanoes are grouped in two forms, the one consisting of circular areas, in various parts of which true volcanic cones arise; the other, consisting of linear groups, sometimes continuous for very great distances. The former are exemplified in the case already given of Jorullo; the latter, involving the loftiest and the most remarkable phenomena of this kind on the globe, will require separate notice, the eruptions that take place from them being on a grander scale, and involving more complicated results.

A volcanic eruption generally commences with subterranean noise, and this is succeeded by dense columns of smoke, impregnated with various gaseous substances, often intermixed with a large quantity of aqueous vapour. Then follow showers of ashes, sometimes accompanied by large masses of rock, which are vomited forth with fearful noise and with enormous force. While these substances are thus being expelled from the hollow cup-like cavity at the summit of the cone, which terminates the volcano, melted rock (lava) at the same time issues either from a breach in the side of the crater, or from some fissure opened on the sides of the mountain. The order of the phenomena is not indeed invariable, but this may be considered as a general account of an ordinary eruption. In those cases in which the volcanic cone rises above the snow line, the heat of the mountain immediately before an eruption is often so considerable, that the snow melts with extreme rapidity, so that the eruption is preceded by torrents of water, often destroying houses, estates, and even whole towns, at a great distance from the volcano.

95 *Volcanic Products.* — To illustrate the true nature and relative importance of these different products of volcanic action, it may be worth while to consider separately the three very distinct kinds which may be designated as gaseous, including smoke and aqueous vapour; solid, consisting chiefly of ashes often in a minute state of division; and liquid matter, consisting of that molten rock so well known under the name of lava. Vivid sheets of flame have been frequently seen during volcanic activity, rising to a great height in the air. Many such appearances of flame are indeed considered by Humboldt as being due to reflections from burning matter projected high in the air during the eruption, and to ascending vapours illumined by the fire within the crater itself, rather than to true flame arising from the combustion of hydrogen. In some cases, however, as at Baku, there seems no doubt that columns of flame have risen to a sufficient height to be visible to a distance of twenty-four miles.

Under ordinary circumstances, the quantity of steam given off in puffs during an eruption is very considerable, and takes place at intervals of from twenty to thirty seconds. The greater part of the vapour consists of pure water, but gases are also erupted at the same time, consisting partly of carbonic acid gas, but including chlorine, nitrogen, sulphuretted hydrogen, and sulphurous acid. Sulphuric and muriatic acids, together with common salt and muriate of ammonia, are mixed occasionally with the pure water. The quantity of products of this kind that are thrown out in a single eruption are certainly very large, but cannot possibly be estimated; for, in many instances, such substances continue to be erupted for a very long period, especially in the case of volcanoes of moderate elevation, which thus seem to connect themselves with those instances of almost perpetual activity already described. The ashes ejected during eruptions differ greatly in every respect, not only in quantity, but also in the mode of eruption, being sometimes reduced to such extremely fine dust, that when thrown into the air, they rise through several successive strata of the atmosphere, in quantity sufficient to be transported by various atmospheric currents to almost equal distances, in different and even opposite directions, while at other times they fall back at once upon the volcano, assisting to raise its cone to a still greater height. In the latter case, the ashes are generally of moderate dimensions, and one third of the height of Mount Vesuvius is composed entirely of such material. Examples are not wanting in various parts of the world of the conveyance of fine dust from volcanoes to distances which would be incredible, if the testimony upon which they are recorded were not beyond all question; and, indeed, the cases are now so numerous, that although far from being easily explained, the facts must be taken as bearing upon the most important questions connected with volcanic activity.

As one of the most recent examples of this transport of fine dust through the air, and one which, although sufficiently extraordinary, is among the least marvellous on record, we may mention here, that on the 2nd of September, 1845, at nine o'clock in the evening, a thick cloud was seen advancing with a strong wind from N.W. by W. towards a ship sailing in latitude 61° N. and longitude 7° 58′ W. This cloud, when it reached the ship, covered everything with fine dust. On that same day had commenced an eruption of Mount Hecla in Iceland, at the direct distance of 500 miles from the ship; so that the cloud of ashes must have travelled at a mean rate of fifty miles per hour.

Far more extraordinary accounts than these are recorded of the lofty volcanoes in the Andes, and also in some of those in the islands of the eastern Archipelago. The volcano of Coseguina, on the west coast of Central America, was in eruption in January, 1835, after twenty-six years' repose. On the morning of the 20th of that month, a cloud rose in the direction of the volcano, which, seen at a distance of fifty miles to the south, presented the appearance of an immense plume of the whitest feathers rising with considerable velocity, and expanding in every direction. From that time to the morning of the 22nd, the cloud retained this appearance, but then a line of intense darkness replaced it. Immediately afterwards, a fine white ash was observed to fall, the black line rose rapidly, the light began to fail, and darkness commenced, and soon increased so much, that in half-an-hour it was blacker than in the thickest night. So intense was the obscurity, that men could touch without seeing each other, and the fowls went to roost as at night. This state of perfect darkness prevailed during the whole of that day, and until noon of the following day, at which time objects became visible at ten or twelve yards distance. In this state things continued for two days longer, but for ten or twelve days the light was partially obscured. During the whole time a fine white impalpable dust continued to fall. This fall of ashes was not confined to San Antonio, which, as has been said, was itself fifty miles from the volcano. Still nearer the central point, the darkness commenced earlier, but did not last so long; while in every place in the immediate neighbourhood the ground was completely covered with ashes, varying in thickness from a few inches to upwards of ten feet. The most extraordinary fact, however, with regard to this eruption remains to be told; for not only were the ashes conveyed in the direction of the wind to a distance of as much as 700 miles, at the rate of 170 miles per day, obscuring the sun in the island of Jamaica, and covering the earth with fine dust, but they were carried to windward for 400 leagues, thus proving that they must have reached to an enormous height in the atmosphere by the violence of the eruption. It is also recorded by the captain of a ship in the English navy, sailing in latitude 7° 26′ N., and 104° 45′ W. longitude, at a distance of 900 miles from the nearest land, and 1100 from the volcano, that his ship sailed forty miles through floating pumice, some of the pieces being of a considerable size. The actual amount of force with which such volcanic products as these are ejected, is not very easy to estimate, and the calculations that have been made on this subject are not so accurate as might be wished. That it is enormously great, however, there can be no question; and it is recorded by Sir William Hamilton, that stones were, on one occasion, thrown up so high above Vesuvius as to occupy eleven seconds of time in falling to the level of the crater. Allowing for the difference of atmospheric pressure in a mountain above 3000 feet high, this gives a force equivalent to the pressure of between three and four hundred atmospheres. Another example is recorded of the projection of a mass of rock, measuring 300 cubic feet, (and therefore whose weight was upwards of 200 tons,) from the crater of Cotopaxi, to a distance of nine miles.

The quantity of matter ejected from volcanoes in the form of lava is more readily measured than in either of the cases yet referred to. The lava streams break out in irregular intermitting springs of molten earthy matter, and frequently continue slowly running for days, and even weeks together. As examples of quantity, it may be mentioned, that in 1837, Mount Vesuvius poured forth as much as thirty-four millions of cubic feet, and in 1794, during another eruption, upwards of forty-six millions. In 1669, Mount Etna poured forth nearly a hundred millions; and in 1783, an eruption took place in Iceland, more remarkable for the extent of its lava current than any other on record, the stream having flowed along two channels, one of them fifty miles in length and twelve to fifteen miles broad, the other forty miles long and seven miles in breadth. In the course of this distance the fiery stream filled up a lake and obliterated a lofty cataract, turning the waters of two streams into vapour, and entirely occupying their beds. Although the thickness was very variable, being as much as five or six hundred feet in the narrow channels, and not more than ten feet in the plains, the lowest estimate of the measurement and weight of this mass is not less than twenty thousand millions of cubic yards, or forty thousand millions of tons of matter, poured out of the bowels of the Earth and spread over its surface within the short space of ten weeks.

96 *Distribution of Volcanoes.*—Having considered thus the nature of volcanic action, and of the substances which, under various circumstances are erupted from volcanoes, it remains that we should explain the mode of distribution of these phenomena upon the Earth's surface. The best mode of obtaining a general idea of this distribution is, by examining carefully a globe or map of the world, in which the positions of the various volcanoes at present or formerly active is distinctly marked, and such a map will be found in the atlas belonging to this volume.

The following table will give a notion both of the position of various volcanic groups, and the comparative number of distinct volcanic vents in different regions. It includes about 400 described cases of volcanic cones, many of which, indeed, have not been known to erupt within several centuries; but this does not necessarily remove them from such a list, as it is very possible for the internal fire to slumber for a much longer period between two epochs of outburst. By giving an idea of the actual distances within which the principal groups are placed, as well as the number in each case, perhaps this table will communicate a tolerably distinct idea of the importance of each group. In many cases, however, the volcanoes are very closely congregated in knots about the centre of the district, while towards its outskirts are only a few cones and craters.

List of the Principal Volcanic Groups, with the Linear Extension of each Group.

	Number of Volcanoes.	Linear Extension in British statute miles.
Atlantic Ocean:		
Jan Meyen Island (Greenland)	2	?
Iceland	8	
Azores	2	
Canary Islands	7	?
Cape Verde Islands	1	
Ascension Island	1	
Trinidad Island	1	
Tristan da Cunha Island	1	
West India Islands	10	450
Mediterranean Group:		
Lower Italy	2	?
Lipari Islands	2	
Greek Islands	1	
Red Sea	2	
Indian Ocean (west side):		
Bourbon Island	1	
Mauritius Island	1	
Rodriguez Island	1	
Asiatic Continent:		
Western Asia	3	
Central Asia	2	
Eastern Asia	?	
Asiatic Coast:		
Kamtchatka group	21	900
Kurile Islands group	18	800
Japan Islands group	23	1700
Bonin and Mariana Islands	9	1000
Formosa	3	280
Luzon and the Philippine Islands	21	1000
Molucca Islands	12	700
North-west coast of New Guinea	4	
Sunda Islands Group:		
Floris and adjacent islands to the west as far as Serva	11	600
Sumbawa and others	9	350
Java	43	650
Sumatra	7	900
Andaman Islands	5	600
Eastern Archipelago:		
Groups of islands between New Guinea and New Zealand	4	
New Zealand	2	
Friendly Islands	2	
Pacific Ocean:		
Hawaii (Owhyhee) group	4	
Society Islands	1	?
Marquesas Islands	1	
Easter Islands	1	
Galapagos Islands	1	
America:		
Aleutian Islands	35	1200
North American series	10	2000
Mexico	7	700
Guatemala	38	850
Quito	17	450
Peru and Bolivia	12	600
Chile	22	1200
Tierra del Fuego	3	400
Antarctic Land	3	

Those groups to which no linear extension is marked, are for the most part detached, and exhibit only imperfect communication with any other district. The groups connected by brackets are probably related, but too imperfectly to justify any statement as to their linear extension.

Looking, then, at these volcanoes as offering means of communication between the interior of the Earth and its surface, we find that while the whole number of such vents is larger, by a great deal, than could be anticipated by observations made on the western Continent, there are still very extensive districts of land, and doubtless, also, large areas of the sea bottom in which no such means are afforded for the escape of gaseous or other substances pent up within the Earth. And although it is certainly true that there are many parts, especially in Europe, where abundant proof is afforded of volcanic action during a period antecedent to the present, and thus the extinct volcanoes add much to the surface which we know to have been provided with vents within a comparatively short interval, there is yet daily increasing proof, that however powerful an agent volcanic force may be, it does not directly or necessarily affect the great mass of land upon the Earth. More than half, however, of the coast line of the existing land is covered at intervals sufficiently near to ensure subterranean communication at great depths underground, but the great area of land within the coast, and the sea bottom, so far as we know, is not sufficiently in relation with changes thus induced, as to justify our regarding them as essential to existing conditions. We shall proceed to show in the next chapter, however, that there are phenomena on record which connect this kind of igneous agency with another more directly influencing the general physical conditions of the Earth's surface.

97 *Subterranean Connexion of Distant Volcanoes.*—Many of the volcanic regions referred to, exhibit very distinct relations with each other, although far removed in point of distance, and separated or covered at the surface by rocks of very various character; but the volcanoes in the same system, or within moderate distances, are often so directly related as to exhibit a distinct reciprocation. Remarkable instances of this have been observed in some of the volcanic cones of the Andes, and this relation has also been shown in the case of the two most considerable European volcanoes.

98 *Connexion of Volcanoes with Earthquake Action.*—Earthquakes may be regarded as convulsions of the Earth, of the nature of undulations propagated in various directions from a central point or line beneath the surface of the Earth, and consist of a series of perpendicular, horizontal, and even rotatory motions, following each other in rapid succession, sometimes being so slight at the surface as only to be perceptible by those familiar to the phenomenon, but occasionally producing the most complete and frightful destruction over whole districts of the Earth. The origin of such phenomena must be regarded as an upheaving force, more or less sudden in its effects, and greatly modified by the extent of area over which it has at first acted.

Earthquakes and volcanoes stand in intimate connexion with each other, generally originating in or near the same parts of the Earth, often so distinctly related in order of time and alternation of results, that they are manifestly seen to belong to each other, so that when volcanic action is exhibited on a large scale, as in the linear groups described in the Andes, the Sunda Islands, and elsewhere, the activity of one volcano interferes with the action of another, and the commencement of a great eruption is generally preceded and often accompanied by earthquake undulations. As also we find, that volcanoes are almost confined to the coast line bounding the Pacific, so also, earthquakes are much less frequent in countries forming the central parts of continents. It is, however, by no means the case that earthquake action is really thus limited, only that the undulations are less common and less considerable in amount in these districts than in others nearer the coast.

If we begin by considering the nature of earthquake phenomena, as exhibited in the different kinds of undulations that have been described, and the local effects recorded to have been produced, we shall find that the subject—although one offering great interest to the general reader, and therefore well adapted for works in which continuous narrative is attempted—does not present that magnitude of interest which can entitle it to rank as a world-phenomenon, unless we connect with these local effects, those much more wide, and indeed universal, changes of level of the general surface of land, and of the sea bottom, to the action of which the form and physical features of the whole surface of the Earth are due. We propose, therefore, to consider, first, and somewhat briefly, the local phenomena that enable us to judge in some measure of the nature and extent of the causes in action, and we may then proceed to investigate the effects on a large scale, and the possible causes of the undulation of the surface generally.

In illustration of the important fact of earthquakes and volcanoes being connected phenomena, it is only necessary to refer to those volcanic districts in different parts of the world already described, and their history, so far as that history has been handed down to us. The vicinities of Etna and Vesuvius have been remarkable for many centuries for disturbances of this nature. Most of the cities, not only of Sicily, but also of southern Italy, have from time to time been the scene of destructive undulations, continued at short intervals for a considerable period, sometimes exceedingly sudden, and frightfully destructive. These have been in most cases directly succeeded by eruptions from neighbouring volcanoes, the earthquakes preceding the eruption, and the shocks increasing in violence, until the mountain relieves itself by discharging its contents; so also when volcanoes in constant or nearly constant action ceased to show signs of activity, earthquakes have generally been known to succeed. Thus, Stromboli had an interval of repose for the first time within the memory of man, immediately preceding a series of earthquakes which took place in the year 1783; and thus, also, the volcano of Pasto, in Peru, ceasing to emit a dense, black column of smoke, which had proceeded from its crater for some time, the terrible earthquake of Rio Bamba occurred, during which 40,000 persons perished. Perhaps, however, the best example of this chain of connexion between earthquakes and volcanoes is seen in the series of events which took place in 1811 and 1812, in the western world. The first of these events was the sudden elevation of the island of Sabrina, in the Atlantic, near the Azores, from a depth of 120 feet, the phenomenon being accompanied by violent earthquakes, and a disengagement of smoke and flame. From this time, severe shocks were felt in the Island of St. Vincent, near one of the most active volcanoes in the West Indian Archipelago, and these shocks extended to the North American continent, producing marked results in the valley of the Mississippi. In December, 1811, an earthquake took place in the Caraccas, and another in March, 1812, continuing several days, and entirely destroying the chief city of the province. And lastly, on the 30th April, 1812, the volcano of St. Vincent, which had been quiet for nearly a century, burst out with a tremendous explosion, which extended for 210 miles, into the plains of Calaboyo. This ended the disturbances, connected together at great depths, extending, as we have seen, from the Azores, and felt round the whole of the interior of the Gulf of Mexico.

It is needless to repeat examples of this kind, which all tell the same tale. Most of the great eruptions of modern times have been preceded by earthquakes, and most of the great earthquakes succeeded by volcanic eruptions.

99 *The Nature of Earthquake Movements.*—It has been mentioned that the undulations connected with an earthquake are of three kinds—namely, undulatory, perpendicular, and horizontal; the latter sometimes producing what appear to be rotatory or vorticose movements. Of these, the first kind is the most common and the most harmless, the second is generally very destructive, while the third has rarely been felt, except in the most disastrous and appalling catastrophes.

Earthquakes are occasionally, but not always, accompanied by detonations and loud noise; the kind of noise that occurs is also different in different places, being sometimes rolling, and occasionally like the clinking of chains, sometimes abrupt, like thunder close at hand, and sometimes clear and ringing, as if obsidian or other vitrified masses clashed, or were shattered in subterranean cavities. In the Caraccas, there was heard over a district of 40,000 miles a loud noise resembling thunder, unaccompanied by any shaking of the ground, during the eruption of a volcano more than 600 miles distant; and at the great eruption of Cotopaxi, in 1744, subterranean noises, as of cannon, were propagated at great depth through the Earth for a distance of more than 400 miles.

The undulations of earthquakes are propagated in two very distinct ways, sometimes extending and being exceedingly violent for very great distances in linear direction, and sometimes extending from a focus almost equally in every direction. It is an important fact that the linear direction of great earthquakes generally corresponds with that of volcanic action in the vicinity. It is probable, however, that even in what may be regarded as central earthquakes, the impelling force is situated along a particular line of country always the same in successive disturbances. Most earthquakes follow the direction of the mountain chains in the countries which they traverse, but occasionally they cross this line at right angles; in the latter case, however, the shocks have generally been weak.

As it is important to bear in mind the difference which really exists between central and linear earthquakes, we may here give a short account of important earthquakes in which each of these directions has been observed. Thus, the great earthquake of Lisbon, which took place on the 1st November, 1755, was felt in a circular or oval area of enormous dimensions, commencing apparently in the Atlantic, off the coast of Portugal, and reaching to the West Indian islands, the lakes of Canada, the shores of the Baltic, and the hot springs of Bohemia. This, therefore, may well be considered as central on a very large scale, since a portion of the Earth's surface, at least equal to four times the whole area of Europe, was then simultaneously shaken. This earthquake has been described at great length, and the phenomena were in the highest degree interesting.

Another remarkable instance of a central earthquake, although of far less extent, took place on the 5th February, 1783, in Sicily, on which occasion Calabria, and about 200 other towns and villages, were destroyed within an area of 600 square miles and 100,000 persons perished. This earthquake, although so small in extent, exhibited all the peculiar phenomena of vorticose movement and vertical upheavals frequently repeated, which from their nature must of necessity result in great injury to any buildings on the surface. The surface, also, itself is in such cases rent asunder, and some portions have been removed to a distance in a manner exceedingly difficult to account for.

The earthquakes here described were more or less central, the form of the land disturbed being either circular or oval, and in these cases the progress of the shocks may be compared to that of ring-like waves produced on the surface of still water when a stone is thrown in, or when a solid is lifted from the bottom. Such waves, both in the water and on land, are both wider and fainter as their distance from the centre increases; and thus in the great Lisbon earthquake, while that city was so completely destroyed, others both north and south of it at moderate distances were only partially injured; while in Ireland, although the shocks were distinctly felt, they ceased to be mischievous, and at still greater distances the disturbing force was only visible in its effects on the waves of the sea or the water of deep springs. So also in the Calabrian earthquake, while the country at one particular spot was rent by deep chasms, and so violently shaken that the heads of the largest trees are said to have almost touched the ground on either side, and while not only was no kind of building able to resist the movement, but tracts of land were actually removed horizontally, so that fields planted with different kinds of corn had exchanged situations, yet, at a comparatively short distance, the towns were not injured, and in the country the shock was scarcely felt. It is also a remarkable and interesting fact with reference to central volcanoes generally,' that the disturbances are by no means equal at equal distances from the centre, or universal at all intermediate places, proving both the true wave-like nature of the movement generally, and its partial interruption by the varying elasticity of the different rocks through which it passes.

Linear earthquakes are no less remarkable than central ones, and in some cases their phenomena are even more instructive. In 1837, a shock occurred in Syria affecting a line 500 miles in length by only 90 in breadth; while in South America there have been instances in which 1000 miles of coast have been affected by disturbances which have not been transmitted in an east or west direction to any considerable distance. On certain occasions that have been recorded, earthquakes have been felt at various points along lines of still greater length, and a most remarkable example of this kind occurred in the year 1835, when several towns were thrown down between Copiapo and Chiloe. On this occasion, the whole volcanic chain of the Chilian Andes was in a state of unusual activity, and almost at the same instant the island of Juan Fernandez, 365 miles from Chile, was violently shaken. More than 300 shocks were counted in this district between the 20th of February and the 4th of March, in the year mentioned. Before this, however, in the year 1822, the coast of Chile had been visited by a most destructive earthquake, felt simultaneously through a space of 1200 miles from north to south.

It is unnecessary to multiply examples of this kind, the facts, although very extraordinary, differing but little in different disturbances; and, in point of fact, the multiplication of accounts that have been given of particular earthquakes would not assist the reader in forming any conclusion as to the original cause of such phenomena. It will be more useful to give the general conclusions arrived at, by those who have studied this subject with a view to determine the bearing of earthquake phenomena upon the structure of the Earth's crust. The two most important points that have been determined are these—First, the much wider extent and influence of subterranean movements commencing or connected with earthquakes than is shown by the accounts recorded of those places where the undulation is felt; and next, the nature and amount of the upheaving force exerted, and the permanence of upheavals and depressions of the surface.

100 *Frequent Repetition and Wide Range of Earthquake Action.*—Examples are not wanting in various districts of repeated earthquake disturbances, at places far removed from recent or even recently extinct volcanoes, and some cases of this kind in the British islands, where there is a certain amount of regularity and periodicity in the phenomena, are well worthy of notice. Thus it has been observed, that of a number of earthquakes, occurring between 1842 and 1845, all, or almost all, took place within a few hours of the moon's first quarter, and have reference to great atmospheric changes, but the number of small shocks that have been felt and recorded in Scotland, within the last few years, give a better notion of the minuteness and frequency of such undulations, and render it probable, that if other regions in which elastic igneous rocks are present at the surface were the subjects of equally careful examination, there would be proof of an almost perpetual vibration over tracts of vast extent.

In the years 1841-42, between the 23rd July and 8th June, no less than sixty shocks have been recorded by Mr. Milne, as felt at Comrie, in Perthshire, twelve occurring on the 30th July, and the rest distributed at irregular intervals, varying from some hours to two months. Between the 1st of July, 1842, and 1st of July, 1843, thirty shocks were felt in the same spot, but at other places in the British Islands, within the same period (although not at the same time), other earthquakes were observed, some of them not inconsiderable in extent, the most remarkable being on the 17th of March, 1843, when Lancashire, Cumberland, Dumfriesshire, the Isle of Man, Belfast, and even the Channel Islands (Jersey and Guernsey), were all subjected to a considerable subterranean movement, variously described as resembling that of a ship in a heavy swell, even inducing nausea, and as like a loaded cart passing along a street. This earthquake was not felt at Comrie, although certainly much more extensive than many of those recorded at that place.

The observations continuously made in Perthshire, showed in the succeeding year (between August 1, 1843, and September 4, 1844) thirty-seven shocks, the most severe of which were on the 25th August, 1843, and 14th January, 1844. Of these, the earthquake of the 25th August was felt simultaneously, and with about equal intensity, over an area of one hundred square miles, and on the 12th June, 1844, when no shock took place at Comrie, a movement sufficient to excite general attention was recognised in Huntingdonshire and adjacent counties of England.

What is remarkable in these cases, is the very frequent repetition of small and strictly local vibrations. Such phenomena are no doubt related to the more widely known and frightful disturbances by which whole towns, with their population, have been in a few seconds destroyed, for these have often had scarcely wider range, and the shocks are not more frequently repeated.

But if some earthquakes have been thus limited, others again have produced results over a vast area. The great earthquake of Lisbon has been already referred to, and other similar if not equally disastrous occurrences have had an equal extent. It appears, in fact, that the propagation of the wave to which the vibration is due, is only limited by the nature of the rocks through which it passes, and the original circumstances under which the shock was produced.

Many cases have been recorded in various parts of the world, tending to show, that where once earthquake action exhibits itself, it is likely to recur. The slighter and more frequent the vibrations, also, the less probability there seems to be of any serious disturbances, but neither this nor any other apparent law can be depended on. We are told by Humboldt, that 'on the coasts of Peru, where rain scarcely ever falls, and where hail, lightning, and thunder are unknown, these atmospheric explosions are replaced by the subterranean thunder, which accompanies the trembling of the earth. From long habit and a prevalent opinion that dangerous shocks are only to be apprehended two or three times in a century, slight oscillations of the ground scarcely excite so much attention in Lima as a hail-storm does in the temperate zone.'*

The danger from earthquake action, and the relations borne to each other by disturbances of this kind at distant spots, are not without important reference to adjacent volcanoes. Among the most remarkable instances on record of an important and destructive earthquake, at a great distance from a known volcanic region, is that of Lisbon, but this city is, after all, not far removed from certain portions of the bed of the Atlantic, where true volcanic eruptions unquestionably occur. Active volcanoes, therefore, though they may perhaps be regarded as safety valves for the country in their immediate vicinity, do not by any means prevent the occurrence of severe earthquake shocks, which thence extend either in a circular or oval area to vast distances, interrupted and checked, it may be, by the condition and nature of the rocks traversed, but not failing to produce some effect on the surface, and on the various works of nature and art there exposed.

Among the most interesting of the permanent results thus produced, not only near volcanoes, but over large continental areas, are those elevations and subsidences which we proceed in the next section to consider.

101 *Permanent Change of Level accompanying Earthquake Action.*— The earthquake of 1835, that destroyed the town of Concepcion, in South America, and which had a north and south range, was felt over a tract of country equal in extent to the distance between the North Sea and the Mediterranean, and during this and other single earthquakes of the same

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* *Cosmos*, Col. Sabine's translation, vol. i. p. 205.

kind, very extensive areas have been permanently affected by small elevations or subsidences. Such movements, in horizontal position, have been also repeated so frequently, that within a period geologically recent, they have upraised large portions of Chile and Peru several hundred feet; and however it may appear by other observations, that permanent elevation by no means invariably attends earthquakes, it must still be generally admitted that some change in relative level is the usual result of continued earthquake action. Examples of the permanence of the change produced during earthquakes may be seen in the condition of some parts of Cutch, near the mouth of the Indus, and other places on the delta of that river, and in a yet more striking instance recorded by a recent traveller in Brazil (Tschudi), to the effect that the bed of a stream, in one spot, is so altered in position, that the water, if it could now be made to occupy its former bed, must rise up a steep incline, having formerly taken the course it did when the land was in a different position, and at a lower level, and the water being now forced to find a new channel.

Although, however, there are few instances of repeated earthquakes without permanent elevation or depression, to a greater or less extent, the proofs of this change of level are often exceedingly difficult to obtain. Some such cases are chiefly valuable and interesting, not from their extent, but because they have occurred in countries often visited, and are supported by historic evidence of recent date. An examination of the present state of the temple of Jupiter Serapis, in the bay of Baiæ, near Pozzuoli, establishes the fact of an elevation of more than twenty feet (and at one point more than thirty feet) in the land on which the temple is built, and of several alternations of level occurring between the third century of the Christian era and the present time. It is not necessary here to repeat the details which have been frequently given with regard to this subject,* but distinct historical evidence is thus adduceable of considerable change of level of the land in the vicinity of the volcanic mountains of Vesusius and Etna, and the evidence reaches almost to certainty, that the elevation sometimes immediately accompanied destructive earthquake action.

Among the striking examples on record, of permanent change of level in earthquake districts, we may also mention the case of Concepcion Bay already referred to, where the ancient harbour, which once admitted large merchant vessels, is now occupied by a reef of sandstone, and a tract of a mile and a half in length, where the water was formerly four to five fathoms deep, is now a shoal, formed of hard sandstone rock. This is supposed to have been caused by the earthquake of 1751.

In almost every earthquake a considerable amount of destruction is caused by slips of earth and partial subsidences, which we have not alluded to, as not offering phenomena of sufficient magnitude to serve our argument; yet

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* Although it has not seemed advisable to encumber the text with those often repeated accounts, the following general conclusions, extracted from Mr. Babbage's account of the Temple (*Quarterly Geological Journal*, vol. iii. p. 218,) may be found useful, and will perhaps be deemed satisfactory, as illustrating the order of the various operations:—

1. The temple was probably constructed about the end of the second century after Christ.
2. A dark incrustation formed round the walls before the temple was ruined, and during a slow and gradual subsidence to a small extent.
3. The temple became filled with volcanic ashes to the height of about seven feet from the floor.
4. A great calcareous deposit formed in the fresh-water lake made by the hot spring.
5. Partial destruction of the temple.
6. Several of the columns corroded just above the calcareous deposit.
7. The area again covered by volcanic ashes to the height of about 10½ feet.
8. The temple again injured, and exposed to partial subsidence below the sea level. The columns perforated by marine animals.
9. Third filling up with ashes to the height of 20 to 35 feet above the floor of the temple.
10. Temple elevated to a height above its present position.
11. Temple laid bare in 1750 by excavations.
12. Gradual subsidence between 1828 and 1845.

some of these have been remarkable, as in the case of an earthquake in Jamaica in 1692, when the harbour subsided so far, that large store houses were after the disturbance buried thirty-six feet under water, and the mastheads of ships, that had been wrecked, were seen together with the chimney tops of houses, projecting above the waves. A tract of land 1000 acres in extent, also sank down, so that the sea rolled in and remained permanently over this spot.

102 *Origin of Earthquakes.*—That an earthquake is the result of violent, and generally convulsive, subterranean movement, of the nature of an explosion, and is often accompanied by the sudden rending of solid rocks, or the sudden expansion of gaseous bodies, there can be little doubt; and thus, although the ultimate cause may remain unknown, the proximate one may be considered as established. Such a movement taking place in a subterranean cavity, is necessarily propagated as a central undulation if the disturbance occur at a single point, but where a considerable distance is connected underground by continuous hollows or vaults, the explosion may be felt as linear in the manner already described. When, also, the wave or undulation commences at a great depth below the surface, and under the ocean, the bed of the ocean will be upheaved, perhaps without fracture, owing to the superincumbent pressure of a lofty column of water; but in this case, the whole column of water must be lifted up, and a sea wave produced. When again the shock passing through the Earth meets the air, a wave of sound may be generated, and thus three distinct waves are produced by a single and instantaneous explosion. The wave produced in the solid mass of the Earth will itself be propagated with very different velocity, according to the nature of the rock through which it passes, and the interruption it meets with.

Whenever, therefore, an earthquake shock occurs, a true Earth-wave is the first and necessary result. This wave, in its rapid transit from the centre or axis of disturbance to the spot where the undulations are finally lost, involves throughout its whole course a movement in space of every particle of matter affected, and the elasticity of each mass or stratum of rock traversed, will influence the mode in which the wave reaches the surface; so that, where a rock near the surface is brittle, there will be a fracture, where it is soft, there will be a manifest upheaval and depression, and these will remain as permanent alterations of level where the actual movement, in one or other direction, is prevented by the falling in or displacement of other rocks from recovering itself. The rate of propagation of the movement will be exceedingly rapid, amounting always to several miles per minute, and varying from twenty to twenty-eight, according to circumstances.

Where the Earth-wave comes to the termination of the solid portion of the Earth's crust under water, and lifts the overlying sea, the elevation may amount to a few feet, perhaps, and the water is necessarily lifted and let fall to this extent. The Earth-wave, however, continuing to pass along and moving more rapidly than this sea-wave, carries with it the small elevated portion of the water, leaving also behind it the waves thus produced, which follow at a short interval. So long as this goes on in deep water, scarcely any effect can be observed at the surface, but no sooner does the wave reach a shoal, or approach the shore, than the earthquake-wave becomes what is technically called a 'forced sea-wave,' which is a narrow ridge of water forced forward by the great wave, and communicating a shock to ships, as if they had struck upon a bank. This wave accompanying a shock upon a coast is not considerable, and as it reaches the coast while the beach is itself elevated by the earthquake, it scarcely appears or is felt as an apparent recession of the sea. It is followed, however, at an interval dependent on the distance of the centre of disturbance, by the great sea-wave, which if the shore be shallow, may roll in with irresistible force, and in its retreat carry with it the fragments torn up and destroyed by the previous earth-wave. Lastly, a sound-wave formed in the atmosphere, moving still more slowly than either of the others, succeeds the earthquake after a considerable interval of time, and like thunder, is only heard when the danger is past, although it often appears to the unphilosophical observer as a fearful addition, almost more to be dreaded than the real undulation.

It occasionally happens that areas of disturbance, or districts exposed to some repeated cause of earthquake, are sufficiently near to be within the range of the same Earth-wave. The various disturbances in that case produce their effects independently, but these may intersect, and either destroy or double each other. The magnitude of the wave propagated in the crust of the Earth, will be increased at the surface according to a general law in mechanics, by which vibrations transmitted in elastic bodies have a tendency to detach the superficial strata.*

103 *Partial but Permanent Elevation at a Distance from Volcanoes.*— While there is little difficulty in comprehending the possibility of various movements of the Earth's surface, where that surface is exposed to the undulations we have described, the case is different, if we find evidence of permanent alteration of level in countries far removed, not only from existing volcanoes, but even from those volcanic appearances which indicate the former existence of igneous disturbance. Such at first sight may appear to be the case with the Scandinavian peninsula and the west coast of the British islands, which afford in various places evidence of elevation, but which have only very recently been recognised as subject even to partial earthquake action.

In Northern Europe there appears to be an area of land whose length is more than 1000 miles, reaching from Gothenberg, in Sweden, to the North Cape, the northern extremity of European land, subject to slow movement. In breadth, this tract reaches across the Gulf of Bothnia, and it stretches in all probability far into the interior both of Sweden and Finland. The elevation increases in amount as we proceed northwards, and it is doubtful whether the amount of elevation is constant during equal periods of time. The result is seen in various ways, but most strikingly in what are called raised beaches or elevated coast lines, and the evidence on which the fact of elevation is proved requires now to be noticed.

So long ago as the commencement of the last century, a Swedish naturalist, Celsius, expressed his opinion that the waters both of the Baltic and Northern Ocean were gradually subsiding, and he inferred from numerous observations that the rate of depression was about forty inches in a century. This view was supported by various facts observed, but controverted by others, such as the absolute permanence of the water-level in some low islands for many centuries without change; it was impossible also that a permanent depression of the level of the sea could take place in the Baltic and the Gulf of Bothnia, without being general throughout those parts of the ocean in which the level was the same. The view of Celsius is not tenable according to the observations that have been more recently made, but the fact of a change in the relative level of land and water seems to be now distinctly proved, and in the year 1807, Von Buch, on his return from a tour in Scandinavia, announced his conviction that the whole country from Frederickshall, in Norway, to Abo, in Finland, and perhaps as far as St. Petersburg, was slowly and insensibly rising. He also suggested 'that Sweden may rise more than Norway, and the northern more than the southern parts.' He was led to these conclusions principally by information obtained from the inhabitants and pilots, and in part by the occurrence of marine shells of recent species, which he had found at several points on the coast of Norway above the level of the sea. He also mentions the marks set on the rocks. Von Buch, therefore, has the merit of being the first geologist who, after a personal examination of the evidence, declared in favour of the rise of land in Scandinavia. The attention excited by this subject in the early part of the pre-

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* Humboldt's *Cosmos*, Sabine's translation, vol. i. p. 192.

sent century, induced many philosophers in Sweden to endeavour to determine, by accurate observations, whether the standard level of the Baltic was really subject to periodical variations; and under their direction, lines and grooves, indicating the ordinary level of the water on a calm day, together with the date of the year, were chiselled out upon the rocks. In 1820-21, all the marks made before those years were examined by the officers of the pilotage establishment of Sweden; and in their report to the Royal Academy of Stockholm they declared, that on comparing the level of the sea at the time of their observations with that indicated by the ancient marks, they found that the Baltic was lower relatively to the land in certain places, but the amount of changes during equal periods of time had not been everywhere the same. During their survey, they cut new marks for the guidance of future observers, several of which were examined by Sir C. Lyell fourteen years after (in the summer of 1834), and in that interval the land appeared to have risen at certain places north of Stockholm four or five inches. Sir Charles Lyell on this occasion convinced himself, after conversing with many civil engineers, pilots, and fishermen, and after examining some of the ancient marks, that the evidence formerly adduced in favour of the change of level, both on the coasts of Sweden and Finland, was full and satisfactory. The alteration of level evidently diminishes as we proceed from the northern parts of the Gulf of Bothnia towards the south, being very slight around Stockholm.

These facts with regard to the shores of the Gulf of Bothnia are paralleled and rendered more clear by what has been observed since in the northern extremity of Scandinavia. It there appears that not only a narrow strip of coast, but the whole of Norway, from Cape Lindesnæs to Cape North, and beyond that as far as the fortress of Vardhuus, has been in course of elevation during a period immediately anterior to the historic period. On the south-east coast this elevation has amounted to about 200 yards, and the marks which denote the ancient line of coast, and which have been seen and measured in many points, are so nearly horizontal, that the deviation from horizontality cannot be appreciated, a circumstance which renders it impossible to account for the change by assuming a number of small local or independent disturbances.*

There are also on our own shores numerous instances known locally as 'raised beaches,' which prove the partial and very considerable upheaval of the coast in Wales, Cornwall, and elsewhere. At Plymouth and in its vicinity, there are remains of a beach sloping towards the sea, of which the maximum height is thirty feet above the present high-water mark, and traces of similar beaches covered with pebbles and shingles and containing the shells of the neighbouring sea are met with all round the coast of Cornwall, some of them rising to fifty feet above the sea, and others only just removed above it; while similar appearances on the Welsh coast show that the change of level has reached there to as much as 1200 feet. The shores of the Irish Sea near the mouth of the Mersey, and the whole coast of Scotland, abound with similar instances, many of which have been recorded in sufficient detail to prove distinctly the general fact.

It would, indeed, appear that no part of the western coast of Europe, from France to the North Sea, is now at the same level as that it possessed some ages ago. The change in most places is, however, gradual, and the amount generally inconsiderable, the most remarkable instances being in the Mediterranean, where many cliffs covered with shells of recent species are not only high above the level of the sea, but extend uniformly for very great distances.

While, however, changes have been going on thus slowly, and for a vast period of years, on the north-western coast of the Old World, the southern extremity of America has been gradually assuming a form which

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* Lyell's *Principles of Geology*, 7th edition, p. 495, *et passim.*

is manifestly due to the action of causes strictly analogous. In South America, indeed, everything is on a grand scale, and all recent causes of disturbance are there exceedingly active; but the examination of the surface with a view to discover, as far as may be, to what its peculiar appearance is owing, has brought to light a series of movements of the nature chiefly of permanent elevation, hardly traceable in other parts of the world. Recent shells—the shells of animals whose immediate descendants of the same race are now living in the Atlantic—are found on the shores from Tierra del Fuego northwards for 1200 miles, and at the height of about 100 feet in La Plata, and of 400 feet in Patagonia. The elevatory movements on this side of the continent have been slow, and the coast of Patagonia, up to the height in one part of 950 feet, and in another of 1200 feet, is modelled into eight great step-like, gravel-capped plains, extending for hundreds of miles with the same heights; this fact shows that the periods of denudation (which, judging from the amount of matter removed, must have been long continued,) and of elevation were synchronous over surprisingly great lengths of coasts. On the shores of the Pacific, upraised shells of recent species, generally, though not always, in the same proportionate numbers as in the adjoining sea, have actually been found over a north and south range of 2075 miles, and there is reason to believe that they occur over a space of 2480 miles in length. The elevation on this western side of the continent has not been equable; at Valparaiso, within the period during which upraised shells have remained undecayed on the surface, it has been 1300 feet, whilst at Coquimbo, 200 miles northward, it has been, within this same period, only 252 feet. At Lima, the land has been uplifted at least 80 feet since the Indians inhabited that district; but the level, within historical times, has apparently subsided. At Coquimbo, in a height of 364 feet, the elevation has been interrupted by five periods of comparative rest. At several places, the land has been lately, or still is, rising, both insensibly and by sudden starts of a few feet during earthquake shocks; a fact which shows that these two kinds of upward movement are intimately connected together. For a space of 775 miles, upraised recent shells are found on the two opposite sides of the continent; and in the southern half of this space, it may be safely inferred from the slope of the land up to the Cordillera, and from the shells found in the central part of Tierra del Fuego, and high up the river Santa Cruz, that the entire breadth of the continent has been uplifted. From the general occurrence on both coasts of successive lines of escarpments, of sand-dunes, and marks of erosion, we must conclude that the elevatory movement has been interrupted by periods when the land was either stationary, or when it rose at so slow a rate as not to resist the average denuding power of the waves, or lastly when it was in a state of subsidence.*

In estimating the value of the different hypotheses which have been offered to account for this remarkable phenomenon of the gradual upheaval of land, it must not be lost sight of, that the change, important as it is in reference to the organic world, is exceedingly small compared with the whole mass of the Earth. It is natural to conclude, however, that the upheaval being so directly connected with volcanic districts, where it is most manifest and considerable, (as in South America,) and occurring elsewhere in spots which are not without occasional earthquake movements, is connected in some way with the heated condition of the Earth's interior. This heat, however, may produce its effect in two ways, either by expanding gases and forcing the crust to be upheaved by their agency, or by the actual expansion of large and thick masses from the increase of heat which they very gradually receive during subsidence owing to the increasing nearness of warmer portions of the Earth.

It has been proved by experiment and calculation, that if a portion of the

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* Darwin's *South America*, p. 246.

Earth's crust, 100 miles thick, and of the expansibility of sandstone rock, were heated 600° or 800° Fahrenheit, this alone would produce an elevation of between 2000 and 3000 feet. It is important to bear in mind these facts, and their bearing on Physical Geography.

104 *Depression over Large Tracts.*—The movement that goes on in the way of elevation over such extensive areas as those we have been describing, and which indeed appears to have acted with regard to many other wide tracts of flat land upon the Earth, is not unaccompanied by partial depression, occurring even in some districts where elevation is the prevailing movement. Evidences of this are seen in submerged forests, or indications of the former growth of trees where the sea now reaches; but other points of evidence, on a much larger scale, are not wanting. If, however, there is difficulty in measuring accurately the relative level of land and water, so as to discover a small elevation, the difficulty of proving similar moderate depression is still greater. In spite of this difficulty, there is not wanting proof that while elevation is going on on the eastern shores of the Atlantic, the western coast offers a converse phenomenon in the sinking down of part of the coast of Greenland for a space of more than 600 miles in a north and south direction. Observations were made on this subject by Captain Graah, during a survey of Greenland in 1823-24, and afterwards in 1828-29, and others by Dr. Pingel in 1830-32. It appears, from signs and traditions, that the coast has been subsiding for the last four centuries from the firth called Tugaliro, in latitude 60° 43′ N., to Disco Bay, extending to nearly the 69th degree of north latitude. Ancient buildings on low rocky islands and on the shore of the mainland have been gradually submerged; and experience has taught the aboriginal Greenlander never to build his hut too near the water's edge. In one case, the Moravian settlers have been obliged more than once to move inland the poles upon which their large boats were set, and the old poles still remain beneath the water as silent witnesses of the change.*

But far more striking, though not altogether dissimilar, memorials of this gradual change are found in connexion with the work of living and dead animals constructing a stony habitation in various parts of the tropical and adjacent warm seas. Here the coral animals begin to build in moderate depths off the coast, either of the mainland or the innumerable islands of those seas, and appear to flourish best where most exposed to the ceaseless and violent dash of the waves. Increasing with enormous rapidity, the living wall or reef soon expands laterally, but is not continued downwards to a greater depth than about thirty fathoms, except in the case of small and detached individuals of different species.

Now, it appears that in spite of this limit of the depth of living coral reefs, vast areas are interspersed with such reefs, so that in the space of ocean extending from the southern end of the Low Archipelago to the northern end of Marshall Archipelago, (a length of 4500 miles,) every island, with one exception, is atoll-formed, atolls being circular groups of coral, with a salt water lake within them, the water within the lake being generally very shallow, while almost immediately outside the island, the depth is very considerable, and sometimes unfathomable. To give some idea of the true extent of phenomena of this kind, we may mention that some of these atolls are oval-shaped, measuring from fifty to eighty miles in length, and nearly twenty miles in breadth, while one extensive bank (the Chagos bank) presents all the characteristics of an atoll, except that it does not reach the surface, but is completely submerged. The longer axis of this bank measures ninety miles, and the shorter as much as seventy; its central part is a level, muddy flat, between forty and fifty fathoms deep, surrounded on all sides by steep mounds, rising from twenty to thirty fathoms, with a breadth of from five to twelve miles, and the whole bank is bordered by a wall about a mile wide,

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* Lyell, *ante cit.*, p. 506.

rising to within five or ten fathoms from the surface. At a distance of a mile outside this wall, the depth of the sea is 200 fathoms.

In addition to these atolls, coral reefs of a more continuous nature extend as barriers at some distance from the coast line of Australia, and other large islands. These are called barrier reefs, and resemble atolls in the depth of the sea outside their outer wall, and also in having a lagoon channel. These are also of enormous extent, extending on the west coast of New Caledonia for 400 miles, at a distance of eight leagues from the shore, and on the north-eastern part of Australia for 1000 miles, averaging from twenty to fifty miles from the shore.

In addition to these two kinds, there is a third kind of coral reef, not unusally found fringing volcanic islands in the Indian Ocean. These have no lagoon channels, they are narrow, often not more than fifty to a hundred yards wide, and they are less deep than those already described.

The cause that has given to atolls and barrier reefs their characteristic forms is supposed by Mr. Darwin to have been the gradual subsidence of portions of the bed of the ocean over large areas, and is partly deduced from the consideration of these two circumstances—namely, that reef-building corals flourish only at limited depths, and secondly, that vast areas are interspersed with coral reefs and coral islets, none of which rise to a greater height above the level of the sea than that attained by matter thrown up by the waves and winds. The foundation of each reef is assumed to have been rocky, but it cannot be thought probable that the broad summit of a mountain lies buried at the depth of a few fathoms beneath every atoll, with scarcely a point of rock projecting above the surface over so wide an extent as that in which these phenomena have been traced. Much other evidence in favour of the same view is adduced by Mr. Darwin, in his admirable work *On Coral Reefs*, which is accompanied also by a coloured chart of all such reefs and islands, one colour marking those districts in which barrier reefs and atolls occur, and another indicating the fringing reefs only.

It appears, then, as the general conclusion with regard to this subject, that when these two great types of structure—namely, barrier-reefs and atolls on the one hand, and fringing reefs on the other, are thus laid down in colours on map, a magnificent and harmonious picture of the movements which the crust of the Earth has within a late period undergone, is presented to us. We there see vast areas rising, with volcanic matter every now and then bursting forth through the vents or fissures with which they are traversed. We see other wide spaces slowly sinking without any volcanic outbursts; and we may feel sure, that this sinking must have been immense in amount, as well as in area, thus to have buried over the broad face of the ocean every one of those mountains, above which atolls now stand like monuments, marking the place of their former existence. Reflecting how powerful an agent, with respect to denudation, and consequently to the nature and thickness of the deposits in accumulation, the sea must ever be, when acting for prolonged periods on the land, during either its slow emergence or subsidence; reflecting, also, on the final effects of these movements in the interchange of land and ocean-water, on the climate of the Earth, and on the distribution of organic beings, it may be fairly assumed, that the conclusions derived from the study of coral formations are amongst the most important that can be presented to the consideration of the physical geographer.*

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* Darwin *On Coral Reefs*, p. 148.

CHAPTER VIII.

STRUCTURAL PHENOMENA OF THE EARTH INDICATING IGNEOUS ACTION.

§ 105. Nature of igneous rocks in general. — 106. Extinct volcanic regions. — 107. Ancient lava currents and other products of extinct volcanoes. — 108. Other igneous rocks not volcanic. — 109. Metamorphism. — 110. Dykes and mineral veins.

NATURE of Igneous Rocks in General.—The igneous phenomena and their results, so far as we have yet considered them, are limited to the Earth's surface, and give little or no insight into the actual structure of any portion of that superficial crust which it is the object of geologists to understand and describe. Thus, we have seen that volcanoes, although of great interest and importance in the general economy of nature, are too few in number, and occupy too small an area, to affect the whole area of land to any considerable extent, and though, no doubt, those elevations and depressions that we have discussed, and which are connected with volcanic action, are of vast effect in their general result, when continued for a sufficient time, yet even these, in the short space of human history, must have been totally insignificant in modifying the general surface. But we must now carry our investigations somewhat farther, and we shall soon discover that while igneous action is not confined to one district or one period at present, but affects various points of very wide tracts, and lasts often in the same tract for an apparently indefinite period, there are many other parts of the Earth where, beneath the surface and in the rocks that are offered for investigation, proof may be obtained of igneous action, either directly or indirectly, and the usual results may therefore be looked for in the way of former elevation and depression, as well as additional results derived from the disturbance of material in a hardened state by violent mechanical force. In the present chapter we may consider with advantage these points, and thus obtain an insight into one very important department of geology, strictly so called—namely, that of mechanical rocks not left in their original condition of mechanical apposition, but altered by the action of heat or chemical forces; and of other rocks which offer no appearance whatever of mechanical origin, but, on the contrary, seem to have formed part of the original skeleton and framework of the globe, presenting themselves in the central axes of mountain chains, or in the long-exposed and weathered surface of granitic bosses, or rolled blocks broken from the parent rock and transported to a distance.

The various circumstances under which such rocks are presented—the evidence of igneous activity at very early periods of the Earth's history, as well as at more recent, but still distant times—the structural peculiarities of various igneous rocks, and the structural changes produced by them—these, together with the phenomena of segregation, and the collecting of various substances into veins and fissures, whence they may be extracted for the use of man, will, when explained, enable the student to comprehend something of the condition of a portion of the Earth, and form fit subject-matter for careful study.

106 *Extinct Volcanic Regions.*—As at present there are certain lines and small areas of volcanic activity, connected with which can be traced a considerable amount of elevation on the Earth's surface, so may we find in many places abundant proof of ancient volcanic agency in heaps of ashes, volcanic

cones and craters, and beds of lava, the burnt-out fires of former times, and the result of eruptions and attendant elevations of which little or no other record is preserved.

Appearances of this kind are not limited to such distinct marks of subterranean fires as we have mentioned, nor must we expect that eruptions that have been succeeded by the frequent denuding action of marine currents can be as manifest and as easily made out as where a vivid flame, a column of smoke, or a current of molten rock, speak to the senses in a language that cannot be questioned. But we need not feel less certain of the former existence of volcanic action in a spot because, at present, there are no eruptions, provided we can discover true erupted products, such as ashes and lava; and it is well known these are occasionally seen where there are absolutely no indications whatever of igneous disturbance at the surface, although, in other cases, the form of ancient volcanoes is partly preserved in the hills of the district in spite of the time that has elapsed since the period of activity. There may, however, be distinct conditions of igneous rocks where there is no evidence of volcanic disturbance, and it is necessary to consider the extent and value of the various phenomena in each case.

The principal and best known points at which volcanic eruptions have taken place on the continent of Europe, since the commencement of the tertiary period, from volcanoes which have now become totally extinct, are in the valley of the Rhine, between Bonn and Mayence; in the department of Puy de Dôme, in Central France; and on the north-east coast of Spain, at Olot, in Catalonia. All these have been perfectly quiet, and free from the disturbances of volcanic action, during, and probably long before, the existence of man upon the Earth, but all of them exhibit, with the utmost distinctness, series of volcanic phenomena exactly resembling those which are described as characterizing Etna and Vesuvius in modern times. One volcanic district of the Rhine extends for about twenty-four miles from east to west, and from six to ten miles from north to south. The volcanic cones have here been forced up through schistose and micaceous beds of the middle and older Palæozoic periods, and the trachytic lava and basalt have been poured out around the base of the hills, often extending to considerable distances, without much reference to the present configuration of the country. A number of ancient craters, some of which are now lakes, may be observed at different points on each bank of the Rhine, but the walls of these craters are usually made up of cinders and scoriæ, and the deep indentions and fractures of the walls often show the points whence a lava current must once have issued. On the whole, however, the lava seems to have been chiefly erupted through cracks and fissures in the subjacent rocks, and to have been spread evenly over the surface, often in very thin bands.

By far the most important feature of the volcanic district of the Rhine, though not that which presents itself most prominently to the passing visitor, is the great extent of the basaltic platform, partly in the Duchy of Nassau, and extending on the right bank of the Rhine, but reaching still further to the east, and forming the hills called the Vogels Gebirge. In the former district, indeed, the basalt is covered up in many places by a remarkable bed of lignite, or brown coal—but not less than 1000 square miles of country in the neighbourhood of the Rhine have been in former ages overwhelmed by a flood of lava, probably spread out beneath the waters of an inland lake long since dried up. The thickness of the bed is not generally considerable.

A district in Central France—in former times the seat of subterraneous disturbance—reposes, or, rather, rises out of a granitic platform: the Mont d'Or, the most conspicuous of the volcanic cones, rising suddenly to the height of several thousand feet, and being composed of layers of scoriæ, pumice-stones, and fine detritus, with interposed beds of basalt. A considerable number of minor volcanoes form an irregular ridge on the platform, and extend for about eighteen miles in length, and two in breadth. They are usually truncated at the summit, where the crater is often preserved entire, the lava having issued from the base of the hill; and the lavas may often be traced from the crater to the nearest valley, where they usurp the channel of the river, which in some cases has since excavated a deep ravine through the basalt. In Catalonia, the eruptions have burst entirely through secondary rocks, and the distinct cones and craters are about fourteen in number, but there are, besides, several points whence lava may have issued. The volcanoes are most of them very entire, and the largest has a crater 455 feet deep, and about a mile in circumference. The currents of lava are, as usual, of considerable depth in the narrow defiles, but spread out into thin sheets over the plains; the upper part is scoriaceous, further down it is less porous, and at the bottom it becomes prismatic basalt, about five feet thick, resting on the subjacent secondary rocks. In addition to these, many other parts of Europe, especially in Bohemia, Moravia, and Hungary, exhibit remarkable and extremely interesting examples of extinct volcanoes. Some of these are well known for the hot springs which rise out of the ground in the vicinity, or the hills of volcanic products which characterise the landscape, and of this kind are Carlsbad and Toplitz. Others are near existing volcanoes, but have still all the peculiarities of those which are extinct, and amongst this latter kind are numerous instances in the Greek Archipelago.

It appears from the investigations of various travellers that the western part of Asia and the peninsula of India exhibit the phenomena of recently extinct volcanic action on a scale far grander than is known in Europe, for in these countries the lava has been poured out over an area of many thousand square miles, and rests in flat tubular masses upon the country. The volcanoes of Asia Minor are still in a state of disquiet, and the elevation of the chain of the Caucasus has doubtless been continued to within a very recent period; while so closely does the past approach the present in this part of the world and in America, that it is often difficult to decide to which period many of the phenomena must be referred, and it has happened even in Europe, that volcanoes, supposed to be extinct, have once more burst forth, and apparently with tenfold violence, after a long period of repose.

The coast of Antrim, presenting the magnificent basaltic columns of the Giant's Causeway, and an important adjacent district in Scotland as well as Ireland, have long been celebrated as exhibiting very remarkable instances of the protrusion of large quantities of molten rock in former times. In the part of Ireland alluded to, there are many hundred square miles of country, extending from the neighbourhood of Belfast to Coleraine, in which a considerable series of rocks of the secondary period, terminating with the chalk, have been covered in this way. On the coast, especially towards the north, the basalt is seen capping the chalk, which is usually much altered and hardened into limestone, and the flints are reddened as if burnt near the contact. In other places, clayey or shaley beds are changed into hard siliceous rock, and sometimes indicate crystalline structure; while in others, again, as at Ben Evenagh and elsewhere, the basalt assumes a character of extreme grandeur, and successive stages of ponderous and shapeless masses rise to the base of the steep basaltic summit, and there break into pinnacles and precipitous cliffs. But in the interior of the country, the protruded rock, although present, sinks to a low level, and along the western shores of Lough Neagh and Lough Beg is so much concealed as to appear only in isolated lumps or small ridges, rising here and there above the surface. In many places, indeed, it is evident that the softer parts of the rock have been carried away, and that the whole of the detached portions were formerly continuous; and this is not to be wondered at, when we consider that the mineral composition and relative hardness is very variable, and that the whole district has been exposed to diluvial action, and to the denuding force of running water. It is not easy to account for the occurrence of these large masses of igneous rock in the north-east of Ireland, or to connect them with any focus or centre of eruption. They have probably been forced through wide cracks formed in the subjacent strata, and thus belong to the class of phenomena sometimes considered separately from the tabular basalt, and denominated trap veins and dykes. But however this may be, all the true characters of lava are apparent in the rock under consideration, and all the strata discovered in contact with the basalt have been altered by this foreign rock introduced among them. Phenomena almost exactly similar are seen in the Island of Staffa and in some others of the western islands of Scotland, and the picturesque beauty of Fingal's Cave and the Giant's Causeway has been too often described to render any account of them necessary in this place.*

107 *Ancient Lava-Currents.*—It has been proved by the experiments of Mr. Gregory Watts,† that the rock spoken of in the preceding page as *basalt*, is in point of fact, nothing more than lava of ancient date, and although in England basalt and basaltic rocks are confined to certain parts of the country, and to rocks of certain geological designation, they are found elsewhere more generally diffused.

Basalt occurs in the older rocks in two conditions, which may be separately considered—namely, 1st, in the condition of an overlying mass, or of beds alternating with the regular strata; and 2nd, as dykes, traversing stratified and other rocks, and filling up cracks and fissures. In this latter state it often forms the connecting link between the tabular masses and some great subterranean reservoir, although in other cases it does not rise above the surface of the rocks which it penetrates. Its mineral constituents are essentially the same as those of modern lava, but occasionally hornblende predominates, when, from the peculiar colour of that mineral, the name of greenstone is applied to the variety. The most usual characters of the basaltic rocks of England are—(1) their iron-grey colour, approaching to black; (2) their frequent tenacity and hardness (whence their value in making roads); and (3) a sharp and sometimes conchoidal fracture, and a granular aspect, indicating the commencement of crystalline structure. They are very liable to superficial decomposition, in which case the colour changes to a rusty brown, owing to the oxidation of the contained iron, and the decomposition sometimes penetrates a considerable depth into the mass of the rocks, exhibiting spheroidal masses less decomposable than the rest of the rock. There are several beds and overlying masses of trap among the carboniferous rocks of England, very many others which have only penetrated the Silurian rocks, and which, therefore, must have been erupted anterior to the decomposition of the Newer Palæozoic strata. It will be sufficient to allude shortly to the principal instances, in order to give a general idea of the nature of these rocks of intrusion in our own country. Basalt occurs in overlying masses in many parts of the north of England; eminences of this kind have often been chosen for the sites of feudal castles, and at Bamborough, where one of these castles was built, the thickness of the mass has been ascertained, by boring for water, to be seventy-five feet. A remarkable instance of overlying basalt may be observed forming a group of hills near the town of Dudley, in Staffordshire. The rock here has received the name of Rowley rag,‡ from the village of Rowley, situated on one of the highest of the basaltic hills. It is extremely hard and of coarse texture, and has been used for paving the streets of Birmingham; a similar rock is found at a distance, forming the upper part of the lofty hills of Titterstone Clee and Brown Clee, in Shropshire. The trap in these places distinctly reposes on the coal measures, and where it comes in contact with the coal has greatly injured its quality, and reduced it to a sooty state. The toadstone of Derbyshire is a well known rock, apparently interstratified with the rocks of the Carboniferous period in that county, and it offers a very striking example of bedded trap. This toadstone, which had generally been described as repeated in three distinct beds, has been supposed by Mr. Hopkins to be the effect of only one, or, at the most, two eruptions of melted

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* Ansted's *Geology*, vol. ii. pp. 208—213.

† *Trans. Roy. Soc.* for 1804, p. 279.

‡ It was a mass of this rock which formed the subject of Mr. G. Watts' experiments, already described.

rock, and he has endeavoured to show that the several beds, apparently distinct, merely consist of the original one repeated in different parts of the district by faults. The abundance and accuracy of the detailed information offered in support of this view render it difficult to doubt that the conclusion is correct. The determination of this point is of much importance in a country so valuable for its mineral resources, and the more so, because the identification of the limestones and associated lead veins depends on the position of the interstratified volcanic rock.*

Basaltic dykes of very considerable extent traverse the carboniferous limestone in many parts of the north of England, some of them being as much as from thirty to forty feet in width. These dykes are either vertical or very highly inclined, and the basalt of which they are formed is of a greenish-black colour and coarse texture. Sufficient evidence is supposed to exist of their igneous origin, and of the rock having been injected in a melted state, by the altered appearance of the wall of the dyke; for the adjacent coal, in one example, at Walker, in the Newcastle coal-field, is actually converted into coke, which, on one side, was found to be in some places thirteen feet thick, and on the opposite side upwards of nine feet.† But this fact of the coal being completely charred and turned into coke is common throughout the district, whenever a basaltic vein traverses coal-bearing strata.‡ The rocks of volcanic origin, which are most commonly associated with basalt, are those called *trachytic*, or *trachyte*, from their rough feel when rubbed between the fingers. Trachyte is sometimes considered to bear the same relation to granite that lava does to the ancient basalts, and is composed chiefly of felspar, combined frequently with a considerable proportion of silex. It abounds in the volcanic district of the Rhine, and there forms a kind of imperfect building stone, and it is also common in various forms in the Puy de Dôme, where it appears under very similar circumstances. Besides the ordinary form of trachyte as a volcanic rock, it appears yet more frequently in pulverulent masses of pumice, forming what is called *tuff* or *tufa*, which has been found in rocks of all ages, interstratified with fossiliferous beds, but itself rarely containing organic remains. The presence of this tufa invariably marks the vicinity of igneous and erupted rocks, and in this way it is often useful to the geologist, more especially in the older formations.§ It has frequently been attempted, more

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* At Teesdale, in Yorkshire, and elsewhere in the north of England, there are instances of highly picturesque scenery owing to the presence of basaltic rocks in various crystalline conditions. In these cases, the associated limestones are usually altered and converted into marble.

† Conybeare and Phillips' *Geology of England and Wales*, p. 447. It may be observed here that this evidence, though very plausible, is by no means free from objection, and the change observed may possibly be independent of the heat of the basalt.

‡ A still more remarkable instance than that in the text, of the alteration effected in the neighbourhood of a trap-dyke, is related in the *Transactions of the Northumberland Natural History Society*, vol. ii. p. 343. An account is there given of the greenstone dyke on Cockfield Fell, and its effects on the coal strata in one of the collieries of the great north-eastern coal-field. In working the coal towards this dyke, the change was observable at a distance of fifty yards, the coal becoming dull, and losing its quality for producing flame. Nearer the dyke, it has the appearance of half-burnt cinder, and still nearer, consisted of sooty matter, caked together, while close to the dyke the bed was reduced in thickness from six feet to nine inches. This dyke is nearly vertical; it has been traced about seventy miles from south-east to north-west, and is in some places eighteen yards in width; and it is calculated to have spoiled as much as 100 yards of coal along all that part of the seam traversed by the dyke throughout Cockfield Fell. The observation made in the previous note will also apply here.

§ The pumice of commerce can hardly be regarded as a distinct mineral, as it is only a cellular and filamentous state which several volcanic rocks (chiefly trachytes) are capable of assuming. It is not met with in all volcanic districts, and seems to be erupted only under peculiar circumstances. Vast quantities have been quarried at the foot of Cotopaxi, one of the celebrated volcanoes of the Andes, and it there occurs in beds distinctly stratified, and is often associated with obsidian. The principal localities in Europe in which it abounds are the Lipari Islands, and some of the islands in the Grecian Archipelago, Iceland, and the extinct volcaic of the Rhine. It is also found in Teneriffe, and in some of the volcanic islands of the eastern Archipelago.

especially by the continental geologists, to class the various rocks of igneous origin with reference to their predominant minerals, but these arrangements have never attained any very general acceptance in our own country. There appear to be two series—those in which felspar or hornblende respectively abound—in rocks of each geological period, and these in their most characteristic forms of granite or trachyte, and basalt or lava, are sufficiently distinct, but they pass insensibly into one another by innumerable variations, which demonstrate the similarity of origin of all the unstratified rocks.

It may, therefore, be considered, on the whole, that the occurrence of trappean rocks is a geological event belonging to all successive periods, and affecting all rocks whether stratified or not, but it is also evident, that while no rocks bear more strictly the marks of igneous origin than those called basaltic, even they are sometimes so distinctly stratified as to have formed thin layers alternating with fossiliferous strata of aqueous origin and probably erupted from volcanic vents opening at the bottom of the ocean, as we have reason to believe still happens occasionally. There is, therefore, in these phenomena—which, it must be repeated, connect the rocks of known igneous origin, such as are still from time to time erupted, with the most ancient of those rocks supposed to be plutonic—a still farther and more interesting point rendered clear, the change being even indicated by which the regularly stratified fossiliferous rocks pass first of all into metamorphic, and then into distinctly igneous formations.

These facts with regard to ancient lava currents, erupted at various times and under various circumstances, afford ample proof that volcanic agency, or some very nearly allied force, has acted even during the formation of the lower, and therefore older, of those mechanically formed rocks met with in almost all parts of the Earth's surface. We must, however, now consider other appearances presented, in which igneous action appears clear, though not in the form exhibited in either modern or ancient volcanic vents.

108 *Other Igneous Rocks not Volcanic.*—A very large portion of the underlying rocks in many parts of the world, and almost all the highest peaks of the principal mountain ranges, are composed of rocks of which granite is the type, and which seem to have been upheaved from considerable depths, bearing with them in most cases masses of strata originally deposited horizontally upon them, but in the course of elevation cracked and broken, or otherwise altered, according to the nature of the elevating force and the mechanical condition of the beds themselves. These rocks are apparently igneous, but whether they were ever in actual fusion or not, their particles are now so arranged as to exhibit clearly the action of crystalline forces, and the rocks associated and lifted are not unfrequently penetrated by the granite or crystalline masses, or otherwise affected by them. The effects thus produced are not attributed to ordinary volcanic action, for they are on too large a scale, and too little identical, to bear strict comparison with any results of such action at present. They are, however, not unlike when fairly considered, and afford most useful material for such limited comparison as the case really warrants.

The granitic rocks are very widely spread over the earth, and in most cases they form the underlying portion, with reference to any sedimentary rocks that may appear. This might be proof either of their being the most ancient, or the newest formed rocks, for if the former, they must occupy as they do the lowest position, and if the latter, they may have existed in another form for an indefinite period, although only recently placed in a state to affect or upheave other rocks. It is, however, certain, that they really are of various periods, and although from their extensive range often regarded as the foundation and solid framework of the Earth, they are possibly in the very act of formation far beneath the surface, even at the present day.

Granitic rocks, although by no means always of the same general character, exhibit features which leave no doubt as to their nature, and may be found in several localities in each of the British Islands. Granite also occurs abundantly in other parts of Europe, as in the Scandinavian mountains, the Hartz, the range of mountains separating North Germany from Bavaria and Bohemia, the Alps both of Switzerland and the Tyrol, the Pyrenees and the Carpathians. In Asia it forms the centre of the Caucasus; it occupies a large part of the Himalayan, Uralian, and Altai mountains, and is found also in Siberia. In Africa it appears in Upper Egypt, in the Atlas mountains, and at the Cape of Good Hope: it may also be traced along the western part of the whole of the two Americas; and appears again in the islands of the South Pacific, and in Australia.

But granite is only one form of igneous rock, and many others, some having the same general porphyritic character (crystals embedded in a base), are found in various parts of the earth, either alone or in near association with true granite (quartz, felspar, and mica). Such rocks, under various names, have often been described in distinct groups as peculiar crystalline or chemical products, but many of the peculiarities they present, are probably rather owing to a difference in the rate of cooling of a large mass, than to any original characteristic. Thus, according to the rate of cooling, we might have a large or fine grained granite, or a nearly compact rock: or if the quantity of felspar was very great, and the cooling rightly proportioned, the mica and quartz might be crystallized in a compact earthy or glassy uncrystallized basis. In this way a felspar porphyry might be produced from the same ingredients as ordinary granite, and the various greenstone, hypersthenic, hornblendic, and other mixtures, do not require detailed descriptions in a general account of igneous rocks.

Of the granite and similar rocks presented in the British Islands, some portions in Scotland (Isle of Skye), Cornwall, Cumberland, and elsewhere, have not only forced up other rocks, but have also penetrated the fissures made in them during elevation. This seems to prove two important points—namely, that at least in these cases, the granite was more modern than the adjacent and overlying masses, and also was ejected in a soft or nearly fluid state. Granite veins or dykes, filling up crevices, are indeed by no means rare phenomena, although they had not till a recent period attracted full and complete attention.

The chief field for observation of igneous rocks within the British Islands is in Scotland, where almost every variety is represented. The Grampian and other mountain ranges are entirely composed of granite, and in the adjacent islands it is repeated in all its characteristic features. In Cumberland and North Wales, felspar porphyries take the place of granite to a great extent, and alternate with it. In Cornwall, granite re-appears in large quantity and throws off numerous veins. In the Malvern hills, and those of Charnwood Forest, in Leicestershire, Syenite prevails, while hypersthene rock frequently appears, and sometimes, as at Cuchullin and Carrock Fell, forms pinnacled mountains. The rock called claystone, and claystone porphyry, and various amygdaloidal rocks, also present themselves, varying and complicating the phenomena.

Thus do these igneous rocks present themselves at or near the general surface, in many important districts, and offer for the investigation of the naturalist many striking facts. The various rocks, abruptly rising and exposed at the surface, are often split by deep parallel fissures, sometimes formed into large flattened globes, which put on also a columnar appearance—and sometimes worn into mounds, scaling off in layers at the surface. The same rocks, different only by the circumstances of their formation, are elsewhere split into blocks, which might at first appear rolled or transported from a distance, but which are really only the results of a peculiar decomposition.

All these and many other appearances have been described as, at some times and in some places, characteristic of this group of rock masses, which have indeed little in common either in material or order of arrangement of the material. It is important also, to remark in conclusion, that the mineralogical and other peculiarities are wholly independent of age or position, for we find in opposite hemispheres in totally different climates, and under circumstances perfectly distinct, the same general aspect and the repetition even in minute detail of many common igneous rocks.

109 *Metamorphism.*—The erupted rocks, whether granitic or basaltic, not only act dynamically, shaking, elevating, inclining, and laterally displacing the superincumbent beds, but also modify the chemical combinations of their elements, and the nature of their internal structure; thus forming new rocks. These under the names of gneiss, mica slate, clay slate, granular limestone or marble, and quartz rock, are often very extensive, and are denominated *metamorphic*. The theory of metamorphism is now established with reference to a great variety of rocks, and the nature and amount of change are fully recognised.

Observations made with great care, and over considerable tracts of country, show that erupted rocks have acted in a regular and systematic manner. In parts of the globe most distant from each other, granite, basalt, and diorite are seen to have exerted, even in the minutest details, a perfectly similar metamorphic action on the argillaceous schists, the compact limestone, and the grains of quartz in sandstone. But whilst the same kind of erupted rock exercises almost everywhere the same kind of action, the different rocks belonging to this class present in this respect very different characters. The effects of intense heat are indeed apparent in all the phenomena; but the degree of fluidity has varied greatly in all of them, from the granite to the basalt; and at different geological epochs, eruptions of granite, basalt, greenstone, porphyry, and serpentine, have been accompanied by the issue of different substances in a state of vapour. According to the views of modern geology, the metamorphism of rocks is not confined to actual change effected at the contact of two kinds of rock; but it comprehends all the phenomena that have accompanied the issuing forth of a particular erupted mass; and even where there has been no immediate contact, the mere proximity of such a mass has frequently sufficed to produce modifications in the cohesion of the particles, in the texture of the rock, in the proportions of the silicious ingredients, and in the forms of crystallization of the pre-existing rocks.

All eruptive rocks penetrate as veins into sedimentary strata, or into other previously existing endogenous* masses; but there is an essential difference in this respect between plutonic rocks—granites, porphyries, and serpentines—and those called volcanic in the most restricted sense—trachytes, basalts, and lavas. The rocks produced by the still existing volcanic activity present themselves in narrow streams, and do not form beds of any considerable breadth, except where several meet together and unite in the same basin. Where it has been possible to trace basaltic eruptions to great depths, they have always been found to terminate in slender threads, examples of which may be seen in three places in Germany,—near Marksuhl, eight miles from Eisenach,—near Eschwege, on the banks of the Werra,—and at the Druidical stone on the Hollert road (Siegen). In these cases, the basalt, injected through narrow orifices, has traversed the bunter sandstone and greywacke slate, and has spread itself out, in the form of a cup; sometimes forming groups of columns, and sometimes divided into thin laminæ. This, however, is not the case with granite, syenite, porphyritic quartz, serpentine, and the whole series of unstratified rocks, to which, by a predilection for mythological nomenclature, the term plutonic has been applied. With the exception of occasional veins, all these rocks have been forced up in a semi-fluid or pasty condition, through large fissures and wide gorges, instead of gushing in a

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* This term has been used by Humboldt to designate all rocks formed or modified from within, and therefore, not owing their essential characteristics to mere mechanical action. It includes the igneous and metamorphic rocks of other authors.

liquid stream from small orifices; and they are never found in narrow streams like lava, but in extensive masses. Some groups of dolerites and trachytes show traces of a degree of fluidity resembling that of basalt; others, forming vast craterless domes, appear to have been elevated in a simply softened state; others again, like the trachytes of the Andes, in which Humboldt states that he has often remarked a striking analogy to the greenstone and syenitic porphyries (argentiferous without quartz) are found in beds like granite and quartzose porphyry.

Direct experiments on the alterations which the texture and chemical constitution of rocks undergo, from the action of heat, have shown that volcanic masses (diorite, augitic porphyry, basalt, and the lava of Etna) give different products according to the pressures under which they are melted, and the rate at which they are cooled; if the cooling has been rapid, they form a black glass, homogeneous in the fracture; if slow, a stony mass of granular and crystalline structure, and in this latter case crystals are formed in cavities, and even in the body of the mass in which they are imbedded. The same materials also yield products very dissimilar in appearance, a fact of the highest importance in the study of eruptive rocks, and the transformations which they occasion; since, for example, carbonate of lime, melted under high pressure, does not part with its carbonic acid, but becomes when cooler granular limestone or saccharoidal marble when the operation is performed by the dry method; while in the humid process, calcareous spar is produced with a less, and arragonite with a greater degree of heat. The mode of aggregation of the particles which unite in the act of crystallization, and consequently the form of the crystal itself, are also modified by differences of temperature; and even when the body has not been in a state of fluidity, the particles, under particular circumstances, may undergo a new arrangement manifested by different optical properties. The phenomena presented by devitrification,—by the production of steel by casting or cementation,—by the passage from the fibrous to the granular texture of iron, occasioned by increased temperature and possibly by the influence of the long-continued repetition of slight concussions,—may elucidate the geological study of metamorphism. Heat sometimes elicits opposite effects in crystalline bodies; for Mitscherlich's beautiful experiments have established the fact, that without altering its condition of aggregation, calcareous spar, under certain conditions of temperature, expands in one of its axial directions while it contracts in the other.

Passing from these general considerations to particular examples, we may mention the case of schist converted by the vicinity of plutonic rocks into roofing slate of a dark blue colour and glistening appearance; the planes of stratification are intersected by other divisional planes, often almost at right angles with those of stratification, indicating an action posterior to the alteration of the schist, the latter sometimes containing carbon, and then perhaps capable of producing galvanic phenomena.

Sometimes the contact and plutonic action of granite have rendered argillaceous schists granular, and transformed the rock into a mass resembling granite itself, consisting of a mixture of felspar and mica, in which laminæ of mica are found embedded. We are told by Leopold von Buch, that all the gneiss between the Icy Sea and the Gulf of Finland has been produced by metamorphic action of granite upon the silurian strata. In the Alps, near the St. Gothard, calcareous marl has been similarly changed by the influence of granite, first into mica slate, and subsequently into gneiss. Similar phenomena of gneiss and mica slate, formed under the influence of granite, present themselves in the oolitic group of the Tarantaise, in which belemnites are formed in rocks which have already in great measure assumed the character of mica slate.*

Remarkable instances of metamorphism have been pointed out in the

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* Humboldt's *Cosmos*, Sabine, p. 245—250.

Tyrol, especially on the Italian side, where limestone is altered by means of fissures traversing it in every direction, the intervals and cavities being filled with crystals of magnesia, and the original stratification completely obliterated. Others, not less remarkable, are found also in the cliff on the coast of Cornwall, and in many of the western islands of Scotland.

110 *Dykes and Mineral Veins.*—One of the results of the intrusion of igneous rock, and the consequent change effected in the molecular condition of the rock, is the production of crevices and fissures, which may either have arisen from the absolute elevation and consequent disruption of the mass, or from contraction, owing to the drying or heating of the mass. Generally such crevices will be in two principal directions, the one identical with that of the axis of disturbance, and the other at right angles to that axis—the former will be the longer and more uniform series, but will often include parallel fissures at intervals—the other will be shorter and more irregular, and perhaps chiefly observable at intervals where there seem to have been points of more abrupt violence. It may be considered also highly probable, that since we find two kinds of fissures, one of considerable width at and near the surface, but becoming narrower in descending, while the other continues of nearly equal width to considerable depths, these two kinds are not unfrequently due to different causes, the gaping cracks frequently identical with faults and dislocations of the strata resulting from upheaval, while the more even and regular crevices are connected with deeper-seated disturbances or the gradual contraction of very large masses.

It is convenient to have two names to apply to phenomena which often present themselves in such different manners. The broad cracks, subsequently filled up with matter thrown up from below, or overflowing and so running in, we may call *dykes;* while the narrower crevices, which, though also filled with various minerals, present them in a different way, are called *veins*. Examples of the former, filled with basalt or injected rock, have been mentioned in a preceding section, (see p. 288,) and we have now to consider the latter, which are of great practical importance, as containing not only crystalline earthy minerals, but a large proportion of the most valuable of those ores from which the metals are obtained.

The mineral substances contained in these veins are of two kinds; the one being generally either silex, fluor-spar, or carbonate of lime, all earthy minerals, and generally in a crystalline state, the other consisting of metallic oxides and salts, in greater or less abundance. The latter being the valuable produce of veins, are eagerly sought for and worked: but the others, not exhibiting any trace of metallic ore, possess little economic value. Two classes of veins therefore exist, which are found to differ from each other in various respects, and amongst the rest in compass-bearing and in their inclination to the horizon.

It appears at first, that nothing can be more variable and unaccountable than the relation of the metallic ores in a mineral vein to the circumstances of position of the vein, but in spite of this, there really exists a certain amount of order, and an approach to regularity. In all districts traversed by mineral veins, there are, for instance, what may be called systems of veins, each system being characterized by some peculiarities of position or contents, and each, so far as we can judge, referrible to a distinct period. In Cornwall, there have been described eight such systems, and the same number had been observed by Werner, at Freyberg. In the former district, three of the systems run east and west, and one north and south, while another ranges N.W. and S.E., or N.E. and S.W. Of these, the east and west veins are called *right-running,* because they include most of those which are productive for tin and copper, (the staple minerals of the district,) while the north and south are called *cross-courses,* crossing the first at right angles, and being also productive, but chiefly for lead and iron. The others are called contra lodes, and are few in number. The remaining three classes are also unimportant to the miner, and are usually filled with clay.

The systems of veins in the Freyberg districts are described by Werner, and offer a series of facts somewhat analogous to those observed in Cornwall; but the metals are different, and so also are the prevailing directions of the lodes. The first and most ancient are chiefly north and south, and include those veins from which the chief supplies of lead and silver have been obtained. The second system (contra lodes) are more argentiferous, but much thinner. Their direction is about north-east and south-west. The veins of the third are all north and south, and those of the fourth are at right angles to them, being what are called in Cornwall cross-courses. They both contain lead glance. The others are less important.

In the English lead districts, the systems of veins are much more simple than in Cornwall or Saxony; the direction of the productive veins is, almost without exception, east and west, and they are traversed by cross-courses, not productive, at right angles to them. The underlie is seldom considerable, and it is tolerably uniform throughout the district.

On the whole, and viewed with reference to the whole district, the direction of the productive veins in Cornwall must be regarded as strikingly uniform, and the mean of nearly three hundred observations, recorded by Mr. Henwood, gives 4° S. of W., while the actual direction, in nearly two-thirds of the number, differs but little from the average.*

Lastly, the fact of these veins being filled with various foreign substances, often placed one upon another, in regular order, and repeating nearly the same appearances, under similar circumstances, in the same mining district, is an important proof that they must be referred to some widely acting, if not universal, cause, if we wish to account for them in any rational manner. Electricity, especially in those two important forms, galvanism and magnetism, offers the best and the most satisfactory explanation of the greatest number of the phenomena. The constant action of a force so influential in re-arranging the ultimate elementary atoms of bodies, and causing them to enter into new combinations, cannot fail to produce great changes when acting under favourable circumstances and for a long time. No doubt, however, there have been many causes, proximate, if not direct and primary, which have all acted separately as well as jointly, and these may have operated at different periods, each tending to bring about results for which it was best adapted, and all together assisting in complicating the chain of phenomena now offered for investigation.

Mineral veins are very frequently faults or the result of the displacement of rocks, as well as simple crevices produced by contraction or separation in consequence of upheaval. In both cases they are sometimes filled with soft clay; sometimes the walls of the vein are lined with such clay, and sometimes the interior or contents of the vein are distinctly and at once separated from the walls without the intervention of any clay or other substance.

Veins vary exceedingly in dimensions, from less than an inch in breadth to many hundred yards, and from a length scarcely appreciable to many miles. They traverse all kinds of rocks, but are greatly affected by the kind of material through which they pass. They often cross each other, and are moved in position, the newer vein altering and heaving the older, and their contents are greatly modified by all the mechanical changes to which they are exposed.

The metalliferous ores contained in veins are very numerous, greatly varied, and highly important, as from them are derived the chief supplies of metals used in the arts. Many of the metals, as gold and platinum, are found only in a native state, or alloyed with other metals; others, as silver,

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* See Ansted's *Geology*, vol. ii. p. 256. The actual number of observations tabulated was 295; of this number the direction in 182 instances was between west and south-west, and in 62 others between west and north-west. Dividing Cornwall into ten districts, the mean direction of the veins in seven of the districts is much more south of west than the general mean, as the other three districts chiefly contain the contra lodes.

copper, mercury, arsenic, bismuth, &c., are found occasionally pure or alloyed, and in the metallic state, but more frequently as metallic oxides, or mixed with other ingredients, and in an earthy state. Very common ores of copper, tin, iron and manganese, are the oxides of those metals; other ores, also very common, of copper, lead, silver, zinc, antimony, arsenic, &c., are combinations of the metals with sulphur (*sulphurets*), and others again with carbon and oxygen (*carbonates*); while some metals, such as cobalt, nickel, chromium, &c., are almost invariably found with other metals, such as arsenic and iron. With the common ores are mingled generally smaller quantities of other metallic salts and oxides, from which the numerous varieties presented in the mineral kingdom are derived.

The metalliferous districts of the British islands are chiefly confined to the western and northern parts of England and Scotland, and the eastern part of Ireland. Cornwall alone furnishes the whole of the tin and seven-eighths of the copper obtained, the rest of the copper being from Wales; large quantities of lead are obtained from Durham and Northumberland, Cumberland, Yorkshire, and Derbyshire, although Cornwall, Wales, and Scotland also contribute no unimportant quantity. Large quantities of zinc ore exist also in many of the lead districts of England, but are not now worked to advantage. The iron ores of England are chiefly bedded, and do not, therefore, admit of description in this place, but large quantities of rich oxides (*hæmatite*) are found in Cornwall, and in the northern part of Lancashire. The tin of Cornwall, chiefly in the form of oxide, supplies not only England, but a great part of Europe, a little being obtained from Saxony, and some small mines existing in Sweden and Austria. The island of Banca, in the Indian Archipelago, and the adjacent peninsula of Malacca, also yield a considerable quantity.

Russia is remarkable for numerous and rich supplies of gold, besides silver and lead; these, however, being chiefly important in the more distant easterly provinces of that vast empire. France is comparatively poor in metallic produce. Austria, chiefly in the Tyrol, and Hungary, yield gold, cobalt, iron, lead, silver, and mercury. Scandinavia is rich in iron and copper, while Spain yields mercury at Almaden, and lead and copper in other places. Prussia, with the exception of some parts of Silesia, is comparatively poor, while Saxony is remarkably rich in ores of silver, lead, tin, and cobalt. Various smaller districts in Germany also offer interesting spots to the miner, and amongst these the Hartz is perhaps the most remarkable.

While Europe and Northern Asia thus offer a multitude of places whence metallic riches may be obtained, other parts of Asia, especially India and the country adjacent the Malayan peninsula, together with Southern Australia, are amply provided with similar resources. Nor is America less favourably circumstanced, since Mexico, Columbia, Brazil, and, as has been lately shown, California, are rich in the precious metals, copper, and quicksilver, whilst elsewhere, as in the United States and Canada, the metalliferous minerals already discovered are numerous, extensively distributed, and of great value. Africa again appears to contain several metals, among which gold is not the least important, and many parts of Australia have already yielded large supplies of mineral wealth.

All these mineral districts offer the same general structure, and in most of them similar metalliferous veins are found in the same kind of metamorphic rock. Mountain-chains, or hill-tracts, presenting distinct axes of elevation, mark the line of greatest mineral riches in Great Britain and Scandinavia, the Ural Mountains, the Altai Mountains, the mining countries of the Hartz, of Hungary and Silesia, the Eastern Archipelago and Australia; while the gigantic Cordilleras of the Andes, in South, and the Rocky Mountains in North America, traceable throughout the whole length of the New World, are also remarkable for their metalliferous produce.

CHAPTER IX.

STRUCTURAL PHENOMENA CONNECTED WITH AQUEOUS ACTION.

§ 111. Stratification. — 112. Mechanical disturbance of beds. — 113. Order of superposition of European strata. — 114. Lower Palæozoic rocks. — 115. Middle Palæozoic rocks. — 116. Carboniferous system. — 117. Magnesian limestone, or Permian system. — 118. Upper New Red Sandstone, or Triassic system. — 119. Liassic group. — 120. Oolitic system. — 121. Wealden group. — 122. Cretaceous System. — 123. Older Tertiary rocks of England, France, and Belgium. — 124. Middle and Newer Tertiary formations of Europe. — 125. Tertiary deposits of Asia and America. — 126. Newest deposits of gravel and diluvium.

S*TRATIFICATION.*—There are two classes of structural phenomena observable in aqueous rocks—the one including phenomena of deposition, the other of disturbance; the former presenting the result of many ages of uniform action, similar to that going on around us in every river and on every coast, while the latter marks the intervals of such regular action, and their interruption by upheaving and other forces from below, producing mechanical displacement, and often attended with the incursion of such rocks as we have been considering in the last chapter. As it is the object in the present chapter to study those structural phenomena which are connected with aqueous action, it is manifest that we have to deal with the former of the two classes of facts just referred to.

No one at all acquainted with the coast of our own island, or with the Earth's structure as exhibited in quarries, railway cuttings, coal mines, or other places where that structure is laid bare, can have failed to remark frequent evidence of mechanical deposition and arrangement in the various layers presented, and in the alternations of sand and clay, limestone and sandstone. As little can it have escaped the notice of any careful observer, that these layers are not, for the most part, horizontal, but tilted more or less, and sometimes very considerably, so that in travelling through a country we may, if our route lies in a certain direction, cross the edges of a number of beds in a comparatively short distance, or, on the contrary, may continue on one bed constantly, though that bed is manifestly of no great thickness. In other words, the various beds possess a certain definite direction or length, and a limited breadth, arising from and depending on their inclination to the horizon, rather than their absolute thickness. This is expressed in geological phraseology by the terms *strike* and *dip*, the former meaning the direction in which the edge of the lifted up bed is to be traced along the Earth's surface, and the latter the amount of its inclination to the horizon, which must necessarily be at right angles to the former direction, whatever that is. The geologist, taking advantage of this structure and position of the beds, (the result, no doubt, of the subterranean upheaving motion already described,) learns to connect together appearances in different countries, to extend his knowledge of different beds and multiply very greatly his observations on them, to discover the circumstances of their deposition, by looking at their present aspect, and arrange them in such order that he shall be able to recognise them when he desires to compare those found in distant places.

The materials, therefore, of the Earth's crust being to a great extent rranged in layers, beds, or strata, and appearing to have been deposited from suspension in water, the term 'stratification' includes a very large class of phenomena, and we may employ the expression 'stratified rock,' as a descriptive and distinctive name. The rocks described in the last chapter are, on the other hand, 'unstratified,' for they exhibit neither the appearance referred to, nor any marks of slow subsidence from water.

The general appearance of a stratified rock is that of numerous layers of material of the same kind—whether simple limestone, sandstone or clay, or any mixture of these—forming together a group to which the name of *bed* may be applied, and which differs from the separate leaf-like and irregular layers in presenting characters somewhat more marked at its junction with another such group or bed. Thus, a bed of clay may be of indefinite thickness, and may even form an almost homogeneous mass; but, provided it is separated from similar or dissimilar beds, it is considered distinct, even if resting on, or overlaid by other clay of the same kind; but minute differences of colour or tenacity are generally manifest, and afford sufficient proof of aqueous origin, by producing, in fact, these ordinary appearances of stratification. The word *stratum* (plural, *strata*) is very commonly used as synonymous with *bed*, as, on the other hand, *bedding* is synonymous with *stratification*. When, as frequently happens, several beds or strata rest upon one another, and are possessed of certain common characteristics, having been apparently deposited continuously, the whole together are distinguished as a *formation*, and in this way we speak of the chalk or the London clay as formations, meaning thus to express a higher step in generalization than when we speak of them merely as strata.

But the further investigation of nature shows that there are not only a great many of these *formations*, but that we may occasionally include several of them under more comprehensive titles. In this way, a number of formations together may be collected into a *system*, so that, for instance, the chalk and greensand formations, which have certain characters in common, are spoken of together under the name of the '*Cretaceous System*.' There is a yet higher division also, which is often adopted, and according to which the whole series of strata are collected into three great groups, and this, as its most striking feature, involves a total dissimilarity of fossil remains; and the lapse of a long period of time being supposed to have been the chief cause of this change, the group is sometimes denoted by the term *period*. The expression *series*, is also conveniently applied in some cases, and its use may occasionally be the means of avoiding difficulty or objection.

The whole number of strata thus grouped is exceedingly great, and their total thickness, if added together, would amount to many miles; but as there are no mines so deep, and no mountains so lofty, as to exhibit anything like the half of this thickness, it becomes necessary to inquire what are the means in the possession of the geologist, by which he can attain a knowledge which would thus seem necessarily shut out from him. The explanation of these means introduces another and most important branch of our science.

112 *Mechanical Disturbance of Beds.*—We have said that the beds are generally tilted or removed by some elevatory process from below into a more inclined position, with reference to the horizon, than that in which they were deposited. Now, since we find, on examination, that this elevatory process has acted very frequently during the deposit of the beds that form the series in such a country as England, it appears that the formation of regular strata has been accompanied from the very beginning by the action of forces, sufficiently powerful to elevate, break asunder, or alter the position of the whole mass of matter intervening between the point of application of the force and the surface of the solid matter of the globe at the time, and that these forces, although frequently shifting, were generally exerted in the same or nearly the same direction. It is clear also, that since the rocks have been very frequently consolidated and greatly altered, (partly, perhaps, by chemical and electrical causes, and partly by heat,) after they were deposited but before they were disturbed, and then after this have received the deposits of the next newer period—sufficient time must have

elapsed to allow of all this change, the greater part of which was, doubtless, effected by a process not merely gradual, but even slow.

Of the magnitude and mode of action of these forces, the observations which we are able to make on the rocks exhibited at and near the surface of the Earth, and which we have already considered, enable us to form a very real and useful notion, and although uniform in their nature, they have produced two distinct series of phenomena. From the examination of the first it appears, that the disturbances have often been such as to produce violent and sudden changes upon districts comparatively limited in extent, and that these changes have been accompanied by the eruption of heated or melted matter from beneath the surface. From the other appearances, we learn that tracts of land or of sea bottom of great extent have been the subject of slow and constant alterations of level, apparently without violent changes or marks of disturbance observable at the surface. To the action of the latter forces we must refer the general elevation of low and undulating, and often of mountain, districts, both island and continent, and their occasional depression; while all local disturbances, and the first formation of great mountain chains, belong to the other series, the forces acting at longer intervals and with greater violence over limited tracts.

The geological result of these forces has been, as we have said, to alter considerably the original horizontality of strata, to produce those phenomena which are respectively known as *dip* and *strike,* to cause the existence of *dykes* and *faults,* of *anticlinal* and *synclinal axes,* of *domes of elevation* or saddles, and *valleys of elevations,* while the position of many beds originally horizontal, but now seen lying on the upturned edges of the underlying beds, has introduced the necessity of employing such terms as *conformable and unconformable* stratification. These terms form a part of the technical vocabulary of the geologist, and their meaning requires to be fully understood before commencing any important geological investigations.

113 *Order of Superposition of European Strata.*—It is highly necessary to be acquainted generally with the whole series of mechanical deposits, and although it could hardly be expected that any one country could give a series so extensive, yet it so happens that most of the beds found in any part of Europe are met with also in the British islands.

The following table, though chiefly adapted for our own country, will also serve to give a general idea of the order of superposition of stratified rocks, and of the groups into which they have been collected. It will there be seen that we have a large number of rocks and collections of rocks to consider and compare, and that they have been arranged, as has been already intimated, into three principal divisions, called Periods, and in fourteen less comprehensive groups, called *series,* or *systems.* Of each of these we shall next proceed to give a brief outline, enumerating at least some of the more remarkable facts that have been determined with regard to the materials of which these groups have been made up, and the circumstances under which they are generally presented. It will be observed, however, that whilst in the table we have thought it best to give the order of succession in such a way that the eye would not be deceived in referring to it, it has been preferred, on the other hand, to commence the more detailed description with the rocks lowest in position, and therefore first formed. The reason for so doing will be very manifest when it is considered, that to give a true idea of the order of superposition in a table, the natural position must be observed, while to speak of the rocks themselves, which are derived from each other, the history is best given by commencing with the most ancient formations.

TABLE OF CLASSIFICATION OF ROCKS.

TERTIARY PERIOD.

British.	Foreign Equivalents, or Synonyms, and Chief Foreign Localities.
Modern Deposits.	
Raised beaches. Peat bogs. Submerged forests. Deposits in caverns. Shell marls.	Similar appearances in Northern Europe, Siberia, and America.
Newer Tertiary, or Pliocene Series.	
Upper gravel and sand. Till. Mammaliferous crag. Fresh water sand, and gravel.	These beds, or their equivalents, are known in various parts of Northern Europe and America. Other, but very different deposits, are the newer beds of Sicily. Others, again, are found occupying a large part of South America. Loess of the Rhine.
Red crag.	Subappenine beds. Brown coal (of Germany). Belgian tertiaries (Crag). The Sivalik beds (India) are supposed to belong partly to this period.
Middle Tertiary, or Miocene series.	
Coralline crag.	Touraine and Bordeaux beds. Part of the *Molasse* of Switzerland. Vienna basin. Certain European, Asiatic, North African, and North American beds.
Lower Tertiary, or Eocene series.	
Fluvio-marine beds. Barton clays. Bagshot & Bracklesham sands. London clay and Bognor beds. Plastic and mottled clays, sands, and shingles.	Paris basin. Central France. *Molasse* of Switzerland (lower beds). Belgian tertiaries. Various beds in Western Asia and India. Various beds in North and South America. Nummulitic beds.

SECONDARY PERIOD.

	British.	Foreign Equivalents, or Synonyms, and Chief Foreign Localities.
	Cretaceous system.	
Upper.	Upper chalk with flints. Chalk without flints.	*Scaglia* limestone of the Mediterranean. Maestricht beds. *Senonian* division of D'Orbigny (Craie blanche).
	Lower chalk and chalk marl.	*Turonian* beds of D'Orbigny (Craie tufau). *Quadersandstein* of Germany.
	Upper green sand. Gault.	*Albian* beds of D'Orbigny. *Plänerkalk* of Germany.
Lower.	Lower green sand. *a.* Kentish rag. *b.* Atherfield clay. ? Speeton clay.	*Neocomian* of Switzerland and France. *Hilsthon* of Germany. Pondicherry beds. Bogota beds, South America. ? *Aptian* beds of D'Orbigny. ? *Hils-conglomerat* of Germany.
	Wealden system.	
	Weald clay. Hastings sand. Purbeck beds.	Near Boulogne. North of Germany.

SECONDARY PERIOD—*continued*.

	BRITISH.	FOREIGN EQUIVALENTS, OR SYNONYMS, AND CHIEF FOREIGN LOCALITIES.
	Oolitic system.	*Jura limestone* is the usual continental synonym of our oolitic series.
Upper.	Portland stone.	Lithographic limestone of Blangy.
	a. Limestones with clay and cherty bands.	Honfleur clays. Solnhofen beds
	b. Siliceous sand.	Beds in South of Russia and in India.
	Kimmeridge beds.	
Middle.	Coral and calcareous grits.	*Nerinæan limestone.*
	Oxford clay.	*Argile de Dives.*
	a. Stiff clay.	
	b. Kelloway's rock.	
Lower.	Cornbrash.	*Etage Bathonien* is the name given by D'Orbigny to our lower Oolites.
	Forest marble.	
	Bradford clay.	*Calcaire à polypiers.*
	Great Oolite.	*Calcaire de Caen.*
	Stonesfield slate.	
	Fullers' earth.	
	Inferior Oolite.	
	Liassic system.	
	Alum shale.	
	Marlstone.	
	Lower lias.	*Calcaire à gryphites.*
	White lias.	
	Upper new red sandstone, or Triassic system.	
	Bone bed of Aust cliff.	
	Variegated marls, with salt and gypsum.	*Keuper marls,* or *Marnes irisées.*
		Muschelkalk.
	Variegated sandstones.	*Bunter Sandstein,* or *Grès bigarré.*

PALÆOZOIC PERIOD.

BRITISH.	FOREIGN EQUIVALENTS, OR SYNONYMS, AND CHIEF FOREIGN LOCALITIES.
Magnesian limestone, or Permian system.	
Magnesian limestone.	*Zechstein.*
Dolomitic conglomerate.	*Kupfer-schiefer* and other shales.
Lower new red sandstone.	*Rothe-todte-liegende.*
Carboniferous system.	
Coal measures. *a.* Gritstones. *b.* True coal-measures. *c.* Freshwater limestone of Burdie House, near Edinburgh.	The coal-measures occupy an important place in various parts of the Continent, in Belgium, France, the Rhine, South Russia, and also in North America, in various parts of Asia, and in Australia. The foreign synonyms are, *Steinkohlengebirge, Terrain houillier, Terrain carbonifere,* and *Terrain anthraxifere.*
Millstone grit. *a.* Coarse gritstones. *b.* Laminated shales.	The millstone grit is generally a bed of subordinate importance out of the British islands.
Carboniferous limestone. *a.* Bands of fossiliferous limestone. *b.* Shales (*Calp, Culm*).	The *Kiesel-schiefer* of Germany is an equivalent of the carboniferous limestone. The Belgian limestone beds, and others in Northern Bavaria, are in the same part of the series.

PALÆOZOIC PERIOD—*continued.*

BRITISH.	FOREIGN EQUIVALENTS, OR SYNONYMS, AND CHIEF FOREIGN LOCALITIES.
Devonian, or old red sandstone system. Quartzose conglomerates (*Old red sandstone*) in South Wales and Scotland; represented by coarse red flagstones and slates in Devonshire and Cornwall. Cornstone and marl of the old red sandstone. Calcareous slate, limestone, sandy beds, and conglomerates of Devonshire and Cornwall.	Devonian beds are well known in Belgium, the Eifel, Westphalia, and North Bavaria. In Russia, the old red sandstone appears, and contains similar fossils to those found both in the corresponding beds in the British islands, and also in Devonshire and Herefordshire. The Palæozoic beds of Australia are supposed to be contemporaneous.
Upper Silurian series. Tilestone. Ludlow group. *a.* Upper Ludlow shales. *b.* Aymestry limestone. *c.* Lower Ludlow shales. Wenlock group. *a.* Wenlock limestone. *b.* Wenlock limestone.	Silurian strata extend over much of northernmost Europe, and corresponding latitudes in America. They have been found in Brittany, in Westphalia, near Constantinople, and in Asia Minor. In South Africa, the southernmost parts of South America, Australia, and China, different contemporaneous rocks have been determined. In mineral character they are generally distinct from the English beds, but offer no marked characters uniformly present.
Lower Silurian series. 50. Caradoc sandstone. 51. Llandeilo flags.	

114 *The Lower Palæozoic Rocks.*—The rocks of the Palæozoic or older period are remarkable for possessing a certain striking uniformity of mineral character, in various very distant parts of the globe in which they have been examined. They either rest at once upon the granitic framework of the Earth, or pass by a series of insensible gradations from crystalline and altered rocks, which appear to have been originally formed by the decomposition of granite. These latter rocks also were either deposited before any living creature existed upon the Earth, or under circumstances which did not admit of their presence or preservation. The Palæozoic series consist of (1) the group of Lower Silurian rocks; (2) the Upper Silurian rocks; (3) the Devonian or Old Red sandstone system; (4) the Carboniferous system; and (5) the Magnesian limestone or Permian system.

1. *The Lower Silurian Rocks.*—These rocks are best known by the hard, dark-coloured, gritty beds abundantly met with near the town of Llandeilo, in Caermarthenshire, and thence called *Llandeilo flags*, and the sandstones with calcareous bands found on the flanks of Caer Caradoc in Shropshire, and denominated *Caradoc sandstones.* These, the original subdivisions of the Lower Silurian system, are, however, strictly local, and cannot be traced even throughout the northern part of Wales, although remarkably perfect in South Wales and Shropshire. The older Silurian strata thus determined, are found to be repeated under varying mineral conditions, throughout North Wales; they occur also very distinctly, although not to any great extent, in Cumberland and the Lake district; they appear to exist in Ireland; and they are met with in the south of Scotland, and the west of Cornwall. In most cases, the true age is somewhat doubtful, owing to the absence of any satisfactory evidence of condition or superposition.

On the Continent of Europe these rocks may be traced, though not without difficulty, in various parts of Westphalia and from point to point into

Bohemia, and they have been identified near Prague; they appear also in Silesia, and in this way seem connected with blue clays and other rocks, probably of the same age, in Russia, lying horizontally and undisturbed on the gneiss and other altered rocks of those districts. There is a much thicker series of rocks of the same age in Norway.

In Asia, the eastern flanks of the Ural chain seem to exhibit some specimens of the same ancient formations. In Southern Africa, similar rocks have been observed; many parts of North America exhibit them expanded to an enormous extent; and in South America, the frowning precipices of Tierra del Fuego and Cape Hoorn seem to be formed of contemporaneous deposits.

The thickness of the Lower Silurian beds, although extremely variable, is so frequently considerable, that whatever may have been the circumstances of deposition, we are justified in supposing that a very long period of time must have elapsed before the completion of the series. In our own country, this thickness amounts to several thousand feet.

The proportion of argillaceous matter and quartz, but chiefly the latter in its various forms, is, on the whole, much greater than in any newer rocks, and the mixture of calcareous matter less; while the presence of mica is clear proof of the preponderance of granite among those rocks to whose degradation the presence of these slates and sandstones was owing. In the British Islands and very generally in other countries, the group is represented by a greyish coloured sandy stone, often slaty and flaggy. In North Wales the slates have undergone an amount of mechanical pressure so considerable that they are often folded and twisted into the most extraordinary contortions. Such results are, however, merely local.

2. *The Upper Silurian Rocks.*—The country of the ancient 'Silures' in Wales and Shropshire, is the classic ground of these rocks in England, and exhibits the most remarkable and beautiful series of them anywhere discoverable. They are here distinctly a separate group from the Caradoc sandstone, and although their upper beds pass into the Old Red Sandstone of Herefordshire and the neighbouring counties, there can be little difficulty in at once perceiving that they form a great natural series, grouped into distinct formations.

The neighbourhood of Wenlock and Wenlock Edge, and the hill on which Dudley Castle is built, offer the best examples of the lower of these formations, and have given a name to them. They consist of limestone overlying shale, the latter—the *Wenlock shale*—generally of dirty, muddy appearance, and of grey or blackish colour, containing impure argillaceous and calcareous nodules. This is succeeded by an impure limestone, (containing a good deal of argillaceous matter,) the different layers of which are separated by clayey beds.

The uppermost group of the Silurian rocks is best seen at Ludlow and its vicinity, and comprises two beds of shale or mudstone (the Upper or Lower Ludlow shales) with an intervening bed of limestone (the Aymestry limestone) somewhat less argillaceous than that of Dudley. As might be expected, the limestone is sometimes absent, and, in that case, two beds of shale united represent the whole formation. The upper beds of the Ludlow shale pass upwards into sandy beds, and others which contain in incredible abundance the fragments of several small fishes.

These subdivisions of the Upper Silurian rocks are strictly local, and should not be looked for in other districts. In North Wales, the micaceous sandstones near Llangollen, the Denbigh flagstones, and a large series of rocks probably belong to the newer part of this period. In Cumberland, a great proportion of the mechanical rocks must also be referred to the same age; and in Ireland there are extensive similar and contemporaneous groups of strata. In the Border country and other parts of Scotland, there are rocks of this age of uniform character, and much altered from their original condition.

On the Continent of Europe a considerable proportion of the so-called *grauwacké* of Belgium, Rhineland, and Northern Westphalia, similar beds in

Brittany, others in Spain, and others in the Thracian Bosphorus, near Constantinople, have been shown to be of the Upper Silurian age. Other rocks in Northern Europe, in Russia, and Scandinavia, are yet more distinctly identifiable with our own Silurian strata; and in North America, South America, and the Polynesian Islands, there seems good evidence that groups of fossils more or less characteristic and identical with English Silurian species, mark a contemporaneous deposit of a very similar kind.

115 *The Middle Palæozoic Rocks.*—In the typical Silurian district the Upper Silurian rocks pass upwards into a sandy rock which is occasionally micaceous and becomes a flagstone. This rock, under the name of *tilestone,* is now ranked as part of the Silurian series. It appears most properly to belong to the latter; but the doubt that has been felt is a sufficient mark of the perfect passage between these two formations which, in most parts of England, differ completely in mineral structure. In fact, the so-called tilestones, which are often nothing more than hard and coarse sandstones alternating with red shales, pass into and are overlaid by a number of clayey and marly beds, which afford an excellent soil by decomposition, and are locally called *cornstones,* and these again are covered up by thick and extensive masses of conglomerate and coarse sandstone, the conglomerate consisting, for the most part, of quartzy pebbles imbedded in a red matrix, and known as the *quartzose conglomerate.*

The whole together make up the OLD RED SANDSTONE SERIES of Herefordshire and Monmouthshire, and occupy a considerable district on the borders of South Wales, being there developed to a very great thickness.

The Old Red Sandstone does not, however, always retain the same character as that described above:—as we advance northwards in England, the thickness of the bed diminishes, and it loses many of its peculiar features; but it appears again as a thick irregular conglomerate in Westmoreland; and there, as in Herefordshire, the passage upwards from the Silurian rocks appears complete. But it is chiefly in Scotland that we find those huge masses of enormous thickness, from which the common notions of geologists concerning the Old Red Sandstone are derived, and the beds there extend at intervals for 120 miles, fringing the old rocks and attaining a thickness of many thousand feet. They are also continued round the coast, and are found in many of the Western Islands of Scotland.

Of this series there are said to be three subdivisions, and it is not unlikely that these are sufficiently well exhibited in various districts to allow of their being locally determinable. It is necessary, however, to look upon the whole as the result of causes acting during a long and unbroken period, probably corresponding to the middle and upper portion of the Old Red Sandstone of Herefordshire. In North Britain, the whole deposit rests on the gneiss; the lowest bed is a conglomerate of enormous but variable thickness, evidently made up of the broken fragments of the old granitic and porphyritic rocks, rolled and tossed about for ages in a troubled sea, the hardest stones being often rounded into bullet-shaped pebbles, by their long and incessant attrition against each other. These conglomerates, however, are not universal, being sometimes succeeded and sometimes replaced by a series of remarkable bituminous schists, which, in Orkney and Caithness, abound with the remains of fishes, and exhibit also some fragments of vegetables, the whole being overlaid by rocks of marly character, sometimes becoming a mere friable clay. The uppermost beds consist chiefly of quartzose sandstone.

The Old Red Sandstone was formerly supposed to be a local formation entirely confined to the British Islands, and its true importance, as representing a very well marked Geological epoch, has only lately been fully recognised. Although, however, it might well be supposed accidental that so large a series of coarse sandstones should be deposited as we find in Scotland and Herefordshire, a nearly similar series is found in Russia, covering a vast tract of country; and in the Western States of North America, a group has been described strikingly similar to the lower part of the Old Red of Scotland, The beds, now called the DEVONIAN SERIES, which take the place of the Old Red Sandstone in the south-west of England, are for the most part calcareous slates, often sandy, and sometimes alternating with extensive sandy beds, and with imperfect limestones.

In Ireland, the Old Red Sandstone is represented by coarse conglomerates, and occasionally by arenaceous clayey beds.

On the Continent of Europe, although true Devonian strata exist and are abundant, they are so complicated, and the order of superposition is so difficult to make out, that they could hardly have been determined, had not this obscurity been first cleared away by investigations in our own country.

In Belgium, the Devonian limestones pass out of those belonging to the Silurian period without any break of continuity, and appear to include a perfect series, passing, also without any break, into the carboniferous rocks. On the right bank of the Rhine, near Cologne, where Silurian and Devonian beds appear, the whole series is inverted, the Devonian actually overlying the Silurian strata; and, farther to the south, in the north of Nassau, there are extreme contortions, marks of which may be seen at the fortress of Ehrenbreitstein on the banks of the Rhine, near Coblentz, and still more on the banks of the Lahn, going up towards Ems and Nassau. The Russian strata exhibit no such extreme confusion; but they include many rocks totally different in mineral composition from any that are known to be contemporaneous, although they also represent almost every form that the Devonian strata or Old Red Sandstones assume in other parts of the world.

116 *The Carboniferous System.*—The uppermost beds of the Old Red Sandstone and the Devonian series are often found to pass by a succession of shaly beds, or by an alteration of fine conglomerates and shales, into a black imperfect limestone, succeeded by other limestones, less argillaceous, and very soon covered up by extensive and thick limestones. The bottom beds of the series are commonly seen in Ireland, and they are found also in the Isle of Man, where they become flaggy limestones, and they are also probably represented in the carbonaceous rocks of Devonshire. Generally speaking, however, the overlying limestones do not pass into the Old Red Sandstone or Devonian shales by any passage of this kind, but cover them irregularly and often unconformably.

The distinguishing feature of the carboniferous rocks, wherever they have hitherto been found, consists in the very profuse distribution of carbon in various shapes through almost every member of the series. This is shown in the lower beds by the prevalence of carbonate of lime, in the middle ones by the occasional remains of vegetables, and in the upper by the existence of entire beds of carbonaceous matter, commonly used as fuel in this country, and well known as *coal.* None either of the older rocks or those of newer date, can be at all compared with these Palæozoic strata in respect to the abundance of carbon they contain.

Owing in many cases to subsequent movements of dislocation in the districts where these rocks appear, they are often broken up into fragments, and distributed into areas which have the character of basins or hollow depressions. In this way especially, the rocks which contain the largest quantity of vegetable carbon or the 'coal strata' are limited in range, but this is not the only reason for this limitation, since they must have been also greatly confined in the actual area over which such large contributions of organic matter could be accumulated.

The general order of superposition of the carboniferous series seems to have been (1) a widely-spread formation of limestone, for the most part the work of the coral animal; (2) a series of gritstones or coarse sandstones, called the *millstone grit,* alternating with, and sometimes replaced by shales; and (3) a great series of sandstones and shales, containing amongst them the various beds of coal, and also containing thin seams of iron ore, and generally spoken of as the *coal measures.*

The first of these beds is generally called the *Carboniferous* or *Mountain Limestone.* It occupies a prominent place in the Geology of England, and contributes much to the picturesque beauty of Yorkshire, Derbyshire, &c. In the north of Yorkshire, several thin beds of coal are met with in its lower part, although in other districts of England the vegetable remains are chiefly confined to the coal measures. It often abounds in caverns, some of which are of great extent; and, in Derbyshire and elsewhere, numerous mineral veins traverse it and yield a considerable quantity of lead and zinc ore.

The *Millstone Grit* is an important deposit in the north of England, where it occupies an extensive tract of country, and is extremely thick. In the middle and south of England, however, it fades away, and is almost lost, being feebly represented by a thin pebbly gritstone intervening between the true carboniferous limestone and the coal measures. In Ireland, it re-appears in great force in the mountains about Enniskillen.

The *Coal Measures* must be considered with reference to the various districts in which their vast value and importance are chiefly felt. The great North of England or Newcastle coal field is partly covered up by the Magnesian limestone in Durham, and is occasionally worked through this bed. It contains about eighteen workable seams of coal (whose total thickness is about eighty feet) alternating with shale and sandstone, and greatly disturbed by faults and dykes. The coal is the most bituminous and one of the best adapted for economical purposes of any yet known.

The Lancashire coal field occupies a considerable area, and is connected with that of Yorkshire. It includes perhaps the most perfect series of the rocks of the period anywhere existing, and consists as usual of sandy beds and shales, alternating with a large number of coal seams, seventy-five of which (whose total thickness is 150 feet) are described. In its upper part occurs a pale blue limestone of fresh-water origin, which is again met with in other coal fields nearly a hundred miles distant, and appears also at various intermediate points.

The South Staffordshire coal field is remarkable as the only representative of the Carboniferous rocks in that part of England, the Millstone grit and Carboniferous limestone being both absent. It exhibits a great preponderance of shale, and the number of its coal seams is only eleven, but the thickness of one of these is unusually great, amounting to upwards of thirty feet in some places.

The South Welsh coal field contains about ninety-five feet of coal distributed in about thirty workable seams, the most powerful of which is about nine feet thick. The associated shales and sandstones are of very unusual thickness, and they contain besides coal an abundant supply of ironstone ore. A considerable part of the coal in this district is non-bituminous, and distinguished by the name of *Anthracite.*

Besides these, there are numerous smaller deposits of coal in the middle and west of England, and in Wales, all of which possess local importance, but which we cannot now stop to describe.

The basin of the Clyde in Scotland, is no less interesting for its carboniferous deposits than important from their extent and value. In this district, the Old Red Sandstone is the general base of the coal strata, thick sandstones, occasionally containing coal, taking the place of the lower carboniferous limestone. Thin beds of limestone then succeed, and on these rest the great mass of the coal-bearing strata, which greatly resemble the similarly situated beds in England, but which include seams of ironstone ore yet more valuable. There appears, however, to be a freshwater limestone in this part of Scotland underlying the coal measures, and possibly contemporaneous with a bituminous shale in the North Staffordshire coal field.

The coal seams in the Clyde valley amount in number to eighty-four, but they are mostly thin; the coal, however, is good. The total thickness of the deposit is estimated at about 5000 feet.

The coal fields of Ireland are not unimportant, though they have hitherto been little worked. The principal one worked is that of Leinster, and as much as twenty or thirty feet of bituminous coal have been found in another small field near Tyrone. In Connaught there is also a supply of ironstone ore.

France and Belgium both contain a considerable number of coal fields, but they are mostly of small dimensions, and in the latter country are greatly disturbed, inclining at a considerable angle to the horizon, and worked like mineral veins. The French coal fields are all of very small size.

Russia is not without an extensive series of strata of the date of the Carboniferous rocks; and in the northern part of the empire there seems to be a prospect of workable coal, the lowest beds of the system containing (as in Yorkshire) a few seams of variable thickness, but of great value. In the south of Russia, very good bituminous and anthracitic coal is found in considerable abundance, but the beds are much disturbed by faults.

North America contains coal-bearing strata of great value, and of enormous extent, gigantic coal fields existing in the Western States and the British provinces. The coal measures here, as in Europe, form the uppermost part of the carboniferous series, and the number of seams hitherto known is about ten, having an aggregate thickness of fifty feet. There is one bed of thirty feet, worked like a quarry from the surface.

In Van Diemen's Land, and probably in several parts of Asia, there are strata of the Carboniferous period, greatly resembling those of our own island, and consisting of limestones overlaid by coal-bearing strata. Much yet remains to be done in making out satisfactorily the true position of these strata with reference to the well-known Carboniferous series of Europe.

117 *The Magnesian Limestone, or Permian System.*—The coal measures in the north of England usually terminate with, or rather pass into, a sandstone, differing from the ordinary coal grits in being discoloured with oxide of iron, giving it a red colour. This sandstone, which is frequently of coarse texture, and is very irregular in thickness, composition, and extent, is the *Lower new red sandstone* of English Geologists, and corresponds with a somewhat similar mass of contemporaneous origin in Germany, there called *Rothe-todte-liegende*, a name not unusually applied also in England. There is often an apparent break of continuity between the Lower new red and the next superior bed of *Magnesian Limestone*, but this is not universally the case; and marly beds, with thin bands of shelly limestone, unite and amalgamate the two formations. The Magnesian limestone is extensively developed in the north of England, and is there sometimes as much as five hundred feet thick. It receives its name from its mineral composition, which is a mixture of carbonate of magnesia with carbonate of lime. It is a very variable rock, sometimes hard and perfectly crystalline, forming an admirable building-stone, (in this state called *Dolomite*,) and sometimes in thin beds of loose texture—occasionally laminated—here and there oolitic, like the freestones of a later period—and on the coast of Durham possessing a singular concretionary structure, the cliffs appearing as if made up of piles of cannon balls. In this latter case the carbonate of lime would appear to have formed into nodules, and the magnesia is left in a powdery state, filling up the interstices. The Magnesian limestone in the north of England appears to be capped by gypseous marls of no great thickness, and these are often entirely absent; but further south, not only this capping, but the bed itself in its most characteristic form, is absent, and is replaced by a conglomerate, made up of fragments of carboniferous limestone, cemented together by a red or yellow magnesian paste. The Lower new red sandstone, without magnesian limestone, overlies the coal fields of Staffordshire and Shropshire, but is represented in a somewhat different form from that which it usually takes.

The beds intervening between the coal measures and the Upper new red sandstone are not extremely important in England, but are much more widely extended and more manifestly distinguished as a group in various parts of the Continent. In Germany and some parts of France these rocks are of considerable interest; one of the beds associated with the magnesian limestone containing a copper ore that has been much worked. The magnesian limestone series there forms two groups, the lower one argillaceous, and the upper calcareous, the latter being in all cases mixed with a certain proportion of magnesian earth. In Russia this system is developed yet more perfectly than in Germany; it occupies an enormous trough in the carboniferous limestone in the ancient kingdom of Permia, and consists of a great number of strata of very variable mineralogical character. It has been proposed by Sir R. Murchison to denominate the whole series, from its Russian type, the *Permian system.*

118 *The Upper New Red Sandstone, or Triassic System.*—This system of deposits is the lowest or oldest of the middle period, and is distinguished from the earlier formed beds partly by mechanical position, and also very strikingly in the nature of the organic contents. Like those of the Permian system just described, the rocks now under consideration are less perfectly developed in England than in some districts on the continent of Europe. They consist for the most part of an extensive series of yellow or red sandy beds, alternating with red, green, or blue marls, and containing large masses of rock-salt and gypsum, (sulphate of lime,) and although the beds thus characterized hardly admit of distinct subdivision in England, owing to their great similarity in mineral composition, they are elsewhere divided by a band of limestone, (the *Muschelkalk,*) and in that case the lower strata (*bunter sandstein* or *grès bigarré,*) are usually more sandy, and the upper (*keuper*) more marly. A similar difference in the character of the beds obtains also in some parts of England.

The Upper new red sandstone is generally seen spread evenly over the upturned edges of the underlying Palæozoic rocks, which have undergone much displacement before the deposit of this newer bed. The sandstones, generally of moderately fine texture—less coarse at any rate than the Lower new red sandstones—occupy in this way a large superficial area, and are seen in the extensive plains of the middle and west of England, and filling up all the valleys in the carboniferous limestone of the North. Their thickness is considerable, but not very easily calculated.

The continental beds of this period differ in some important points from those of England, but preserve a general analogical resemblance. The lower part, called *Bunter sandstein* by the Germans, and *Grès bigarré* by the French, is a fine grained, solid sandstone, passing upwards into an earthy clay. To this succeeds the *Muschelkalk,* a limestone of rather peculiar appearance, often argillaceous, and not unlike some of the Silurian limestones in mineral character, but sometimes very different, and even becoming extremely bituminous. The *keuper* or *marnes irisées*—coloured marls, often containing vegetable remains—cover up the muschelkalk, and terminate the series. The upper beds of the Upper new red series in England have been identified with the keuper, and are sometimes spoken of as 'variegated marls.'

119 *The Liassic Group.*—The beds of this formation, so called, it is supposed, from their frequent appearance in striped bands or *layers,* may be traced through England, from Lyme Regis in Dorsetshire, by way of Somersetshire, Gloucestershire, Worcestershire, Northamptonshire, Leicestershire, Rutland, and Lincolnshire, to the Humber, and then through the East and North Ridings of Yorkshire to the coast at Whitby. In all this tract the general features of the formation are the same, and from Gloucester northwards, there is an average and nearly uniform breadth of about six miles, the total thickness of the deposit being generally above 600 feet. The rock is little disturbed, and has a regular dip, being conformable to the underlying and overlying strata, except where it comes in contact with the mountain limestone in Glamorganshire and Somersetshire. The lias is generally subdivided into three parts, the lower portion reposing on a thin bed full of fishes' bones, and consisting of a lower limestone containing a large proportion of clayey matter alternating

with shales, often calcareous. These are overlaid by a bed called the marlstone, (a marly limestone of a very pale colour,) and above this there is another and a final bed of tough blue calcareous clay and shale, which passes into sandy beds, and so graduates into the oolites which next succeed. The uppermost bed is sometimes called the Alum shale, and is greatly developed at Whitby, where it is burnt for alum. The lower beds are exhibited best in Dorsetshire, and the marlstone in Gloucestershire.

On the Continent the Lias possesses nearly the same lithological character as in England, but the lower beds are more sandy, and the middle ones more calcareous. The upper marls are the most uniform of the continental liassic beds, and they most nearly resemble the contemporaneous English strata.

120 *The Oolitic System.*—This interesting group of formations is so admirably exhibited in England, and occupies so large a proportion of the surface of our country, that it has received even more than its due share of attention, and was somewhat too prominently put forward in all its numerous and interesting subdivisions, in the first determination of Geological series.

The beds called *Oolitic* (from the Greek words ὠὸν (*ōon*), an egg, and λίθος (*lithos*), a stone,) are usually subdivided into three well-marked groups, all of them characterized more or less by the presence of limestones; the peculiar structure of which (the rock being made up of innumerable small egg-shaped particles) has given its name to the formation. The general character of the Oolitic system in England may be described as consisting of three ridges running N.N.E. and S.S.W., with broad valleys or plains intervening. The ridges in this case represent the escarpments of the hard limestone beds of the Lower, Middle, and Upper group of Oolitic strata, and the plains, the less coherent or softer beds, interposed between them. In this way the series may be traced through England to the east of the Lias, and parallel to that formation; but in many places, more especially in the north of England, the upper series is wanting, and in the south the lower part is indifferently represented. Thus the order of the relative preponderance of different members of the series observable in the Lias is here reversed, the lower Oolitic beds being chiefly developed in the north, and the upper ones in the south.

The principal limestones of the lower series are the *Inferior* and the *Great Oolites*, and these are separated from one another by marly beds, used as fuller's earth, and by a thin flagstone remarkable for its fossils, and called the Stonesfield Slate. Under the Inferior Oolite there are sandy beds, which greatly preponderate in Yorkshire, and contain numerous vegetable fossils. The Inferior Oolite itself contains about forty or fifty feet of freestone; and the Great, or Bath Oolite, which is more important in economic value, presents a large series of excellent building stones, alternating with coarse shelly beds, but sometimes replaced by a thick clay, called '*Bradford Clay,*' At the top of the Lower Oolitic group is a bed called locally the *Cornbrash*, which decomposes into an excellent vegetable soil, and is chiefly made up of clays and sandstones with calcareous nodules.

The central portion of the Oolitic series consists, for the most part, of a thick bed of tough blue clay, called the '*Oxford Clay,*' very widely extended, not only in England, but on the Continent, and overlaid by beds of a more calcareous nature, sometimes taking the form of a true coralline limestone, and sometimes only containing a mixture of calcareous matter in sandy beds. In its most characteristic form, this upper bed (the *Coral rag*) is chiefly seen near Calne and Steeple Ashton, in Wiltshire, and at Malton, in Yorkshire.

The upper Oolites, like the middle ones, consist chiefly of a thick bed of tenacious clay, locally overlaid by limestone. In this case, the clay is called *Kimmeridge Clay*, from a village near Weymouth of that name, where it is well exhibited; and the bed may thence be traced northwards as far as Lincolnshire, and even into Yorkshire, resting on the Oxford Clay, sometimes without the intervention of the Coral rag, and forming the great fen district of Cambridgeshire. Over the Kimmeridge Clay there is in the south of

England a very extensive development of limestone in Portland Island, the quarries of which have been worked for many centuries; but this does not reach farther north than Buckinghamshire. Where best seen, the *Portland rock* includes several bands of coarse, earthy limestone, alternating with a considerable thickness of freestone, and covered up with a bed containing a substance like vegetable mould, in which the stumps and roots of trees are found. This singular stratum, the *Dirt-bed,* is met with over a somewhat extensive area.

North of Yorkshire, the secondary rocks are very rarely exhibited in the British islands, but in two or three valleys in Scotland, and especially at Brora, there has been described a series belonging to the Oolitic period. The beds are not oolitic in structure, and contain but little calcareous matter.

On the continent of Europe, there are many spots in which rocks contemporaneous with the English Oolites resemble them also in mineral character and general appearance. Near Caen the Great oolite and a considerable overlying series have been described by French geologists. Among the Jura Mountains, and even in the Alps, the three subdivisions are preserved as in England, and this is the case also in the north of Europe, while in Russia, the whole series is divided into two portions, the lower being very locally distributed, but the upper part calcareous and oolitic, and widely spread over the country. In the Caucasus the beds of this period are greatly altered, and have been described as primary.

In Asia, the north western part of the peninsula of India has afforded evidence of an interesting group, probably contemporaneous with the Oolites. The beds containing coal in Virginia, formerly described as carboniferous, belong also to the secondary period, and are of the same age as the lower Oolites of Yorkshire, which they resemble.

121 *The Wealden Group.*—Lying immediately on the top of the Oolites and passing out of them so gradually that the actual junction can hardly be determined, there is found in the south-east of England, a remarkable group of fresh-water beds, classed together under the name of 'Wealden,' and consisting of a very thick and varied series of arenaceous beds based on limestones of small extent and peculiar character, and covered by a bed of clay. This whole series may be described as a series of clays and sands with subordinate beds of limestone grit and shale, containing the remains of organic bodies whose condition manifestly shows that they have been subject to the action of river currents, but not to attrition from the waves of the ocean. The subdivisions are found only in some of the southern counties of England, and are not without some interest, the Purbeck, or lower beds, being remarkable for the presence of a shelly limestone taking a good polish, and known as Purbeck Marble, while the Hastings Sand, though of far greater thickness, hardly presents greater complexity. The Purbeck beds, including a fissile limestone, and as many as fifty-five beds of workable limestone, attain in all to the thickness of about 125 feet, and are much disturbed from their original position. The *Hastings Sand* consists at its base of friable sands such as those seen at the cliffs near Hastings, and upon them are found first an extensive series of arenaceous beds containing building stone, and then some bluish grey sandstones, or calcareous grits, of no great thickness, known as the Tilgate beds. The Purbeck strata are chiefly found in the western part of the Wealden district, and where the fractured chalk exposes the lower beds in the vale of Wardour and the other valleys of elevation in Dorsetshire and Wiltshire, while the Hastings sand is found not only in the vicinity of Hastings, where it is exposed on the sea cliff, but also throughout the whole Wealden district.

An upper band of clay, called the '*Weald clay,*' intervenes between the Hastings sand and the Cretaceous group, and is found along the line of the North and South Downs, near the base of the escarpment of the chalk, and again in the Isle of Wight in the same position. It occupies a tract, about six miles wide in the broadest part, between the Hastings sand and newer rocks, and consists of a tenacious argillaceous bed reposing on beds of sandstone and shelly limestone with layers of argillaceous ironstone.

There are in the Isle of Skye, and in one or two places on the coast of France, opposite the Weald of Kent, small patches of strata, nearly of the same age; and in the north west of Germany a considerable thickness of contemporaneous fresh-water beds has been also determined. With these exceptions, the transition from the Upper oolites to the Cretaceous rocks is abrupt, and there is reason to believe that a long interval must have elapsed between the deposit of the two series.

No marine beds are yet determined which can with safety and certainty be referred to the Wealden period. In other words, the period during which these beds were being deposited in England was either occupied by completing some of the Upper oolites in other seas, or else during that time there was a cessation of deposits over wide tracts, owing either to their being above the sea or the bottom of a deep ocean.

122 *The Cretaceous System.*—This group of strata has received its name from the almost universal presence in it of the white chalk (*creta*) which forms its upper division in most parts of Europe. The whole formation has generally been divided into three parts, (1) the Lower greensand, represented both in some parts of England and on the continent of Europe by very extensive and thick beds; (2) the Gault and Upper greensand; and (3) the Chalk; but the two latter groups seem to possess more analogies with one another than they do with the lower division.

The *Lower Greensand* of England is exhibited in a varied but characteristic form, in the cliffs between Folkstone and Hythe, and also near Maidstone, in the county of Kent, and at the back of the Isle of Wight, where it expands so as to occupy a very prominent place in the Geology of the district. Under the name of *Neacomian*, beds of nearly the same age have also been described from the vicinity of Neuchâtel in Switzerland, and from the south of France.

There are some places in the south-east of England where the passage upwards from the Wealden to the Lower Greensand is very difficult to trace, owing to the similarity of the clay beds in the two deposits. Near Hythe this is especially the case, and here also there is an admirable section of the whole Lower Greensand series. A similar, and equally interesting section may be seen in the Isle of Wight, between Atherfield and Black-gang Chine, but there is no passage there from the Weald clay into the Atherfield clay. In the more central counties of England, in Bedfordshire, Cambridgeshire, &c., where the Lower Greensand is still an extensive bed, it is remarkable for little more than its deep red colour, a phenomenon apparently due to the presence of a considerable quantity of the peroxide of iron.

The Lower Greensand of the south of France and of Switzerland consists of calcareous beds of considerable thickness, and in Germany the beds of the same age are represented sometimes by extensive beds of sand, and sometimes by clays. It is not easy to determine very distinctly the identity of date of the different beds of the cretaceous formation in the Pyrenees, the Carpathians, the Caucasus, and the south of Italy; but there can be little doubt that a very large proportion of the whole must be referred to the lower division.

The Gault and Upper Greensand are chiefly exhibited in the eastern and southern districts of England, and there form a well marked group, presenting distinct features.

The *Gault*, the lower member, is best seen near Folkstone, (to the east of the town,) where it appears from the cliff section to be about one hundred and twenty feet thick, and to rest on the Lower Greensand. It is a stiff blue clay, and is mixed with a small portion of iron pyrites. From Folkstone the same clay may be traced, retaining its appearance and peculiar mineral character throughout the east of England, everywhere coming in between the Lower and Upper beds of Greensand. A little to the north of Cambridge it begins to thin out, and on the coast of Norfolk, where it comes out again to the sea, it is not more than fifteen feet thick.

The *Upper Greensand* is somewhat variable both in thickness and in general appearance. It often forms a kind of step at the foot of the chalk, having a small, but well marked, escarpment towards the Gault; but this is by no means always the case, and as it goes northward it loses the cherty character for which it is remarkable in Surrey and the Isle of Wight, and merely serves to separate the Gault from the Chalk. Both the Lower and Upper beds of Greensand have received their name from the prevalence throughout both of them of small green particles of silicate of iron.

The *Chalk* is a very well-marked and interesting formation, both on account of the peculiarity of its mineral composition, and its great uniformity in all respects throughout a very extensive area. It is also remarkable for the layers of flint distributed through it. Above the white chalk with flints there is found at Maestricht a yet newer bed, also of the Cretaceous period.

The lower part of the chalk is somewhat impure, owing to the presence of argillaceous matter and iron with grains of silex, but these disappear in the upper beds; and the silex, instead of being distributed in grains, is collected into distinct layers, each of which appears to have generally collected round some spongeous body as a centre. In this state the chalk is an almost pure carbonate of lime, with a very small per centage of iron.

In some districts on the Continent of Europe, the upper part of the cretaceous system bears a strong resemblance to the contemporaneous beds in England; and true white chalk has been traced not only in France, but in Denmark, Poland, Central Russia, and the Caucasus. Under another form, the beds of this period are found in the South of France and in Italy, there forming hard crystalline limestones and limestones made up of the fossil remains of foraminifera, and other beds; while, in the central plains of Asia Minor, semicrystalline rocks of the cretaceous epoch occupy a prominent place in the Geology of the district. Remarkable beds of the same age have also been described by Sir C. Lyell, and by American Geologists, as occurring in New Jersey and other parts of the United States; but these seem to rest immediately on the oldest Secondary rocks, without the intervention of the Oolites. It does not appear that any true chalk exists in America, but the formation is extremely calcareous, although perhaps chiefly arenaceous.

123 *The Older Tertiary Rocks of England, France, and Belgium.*—It is only of late years that the department of Geology professing to treat of strata newer than the chalk has assumed its due importance, and the reason of this it is not difficult to comprehend, for the Tertiary strata form a far less prominent group in northern Europe than the rocks of older date, and have for this reason been long considered as of inferior importance, and even as mere superficial deposits not worthy of being described as a distinct system. But this relative predominance of older over newer deposits is reversed in the south of Europe, in some parts of Asia, and in South America, where even the newest group of strata has undergone great change of position, and where thousands of square miles of comparatively modern deposits attest the vastness of recent operations.

It is worthy of remark with regard to these strata, that a large proportion of them bear marks of having been formed in the vicinity of extensive tracts of land, and that in this respect they are contrasted with the older rocks, which were for the most part formed at the bottom of deep seas studded here and there with islands, such as these we now find in the Eastern Archipelago. It is also clear that after the termination of the deposits of the secondary period, and probably during a long interval concerning which we have no records, land had arisen from the deep waters; and the bottom of the sea, previously the receptacle of chalky mud, assumed by degrees the outline of the continents now marked out by the mountain chains of Europe, Asia, and America. But, however this may be, the rocks of the Tertiary period in northern Europe are for the most part local deposits, and have been formed either in lakes, rivers, or estuaries, by matter conveyed along by fresh water, or else in narrow confined seas not far from land. Hence it arises that a variety of causes have come into operation, such as irregular depth, sudden and considerable alterations of depth, and others, sufficient to modify greatly the conditions of animal life.

The Tertiary strata of Europe having been thus formed in small areas, do not usually admit of general descriptions, but require the groups to be each separately described with reference to other contemporaneous deposits, but still more with regard to local circumstances.

The Tertiaries of Europe and Western Asia form a very variable series, consisting, in England and Belgium, of stiff clays, alternating with sand and resting on a coarse sand and gravel; and in Paris, of a number of limestones and marls alternating with gypsum and siliceous strata. They are deposited in valleys or depressions in the older rocks, and in England (in the Isle of Wight) some portion of them has been so greatly disturbed, that the beds are actually vertical. This, however, is an exception to their usual position, which is that of beds not much changed from their original horizontality.

The older Tertiaries of England are chiefly confined to three patches, which were originally, no doubt, connected and continuous, but are now detached and contained in trough-shaped hollows in the chalk. These are called, respectively, the London, the Hampshire, and the Isle of Wight basins, and the stiff clay which predominates in them, and which is very abundant near London, is known as the '*London Clay.*' The London clay often, but not always, rests on a series of sandy and gravelly beds, inclosing bands of potters' clay, and to these the name '*Plastic Clay*' has been given; but, in the Isle of Wight, a distinct group of sands forms the base. It is now certain that no mere mineralogical attempt at subdividing this group of strata will succeed; and Mr. Prestwich has shown that the great mass of clay in the lower part of the London series is strictly contemporaneous with the hard sandy beds at Bognor, from which the clays at Barton cliff are separated by no less than 700 feet of sands.

The strata which occupy the Paris basin differ exceedingly in point of mineral character from the beds just described. Over the chalk is usually found a fresh-water deposit of clay and lignite, and this is succeeded either by a coarse sandy limestone containing many fossil shells, or by a siliceous limestone of fresh-water origin, almost without fossils. Next, above these limestones, separated only by a bed of sandstone, is usually found a series of marls, containing amongst them a considerable quantity of gypsum, and in the quarries from which the gypsum has been extracted, (to make Plaster of Paris,) an immense number of the remains of land animals were found during the early part of the present century. Last of all, in the Paris series, there are two groups of marls and sands, one fresh-water and the other marine, developed to some extent, and separated from the gypsum by a thin bed of oyster shells.

The tertiary strata of Belgium are chiefly seen in the provinces of South Brabant and Limburg, and their general character is that of sandy beds containing oxide of iron, alternating with and overlying a series of badly developed marls and limestones. The whole sequence is rarely exhibited in the same locality, but the total thickness of the deposits is not great. At the base of the deposits in many localities, are argillaceous marls, found chiefly in the northern and western parts of the basin. These are of blue or black colour, tenacious, impervious to water, and containing beds of septaria.

In central France, and especially near Auvergne, is a group of sandstones, marls, and limestones, extending for a considerable distance from north to south, and having an average breadth of about twenty miles. Similar deposits, belonging to the older part of the tertiary period, are found near Le Puy, in Velay, and near Aurillac, in Cantal, the latter being, however, remarkable for containing a large proportion of silex, probably derived from hot springs. Many other small beds are met with in the same district.

On the south flanks of the Alps, near Vicenza, in Lombardy, a band of limestone occurs, and another at Monte Bolca, both of the older Tertiary period, and both remarkable for containing remains of organized beings, chiefly fishes. The beds here are marly limestones, interstratified with thick beds of compact limestone, and the whole series is overlaid by tabular basalt.

There is evidence showing that many parts of Greece and Asia Minor were the recipients of important deposits, apparently from some great fresh-water lake, not long after the termination of the chalk.

124 *Middle and Newer Tertiary Deposits of England and Europe.*—Overlying the older Tertiaries in England there is little more than a heap of gravelly strata, almost exclusively confined to the neighbourhood of the Eastern Coast. These accumulations are called 'the Crag formation,' and they appear to belong to a somewhat extended period, and to be divisible into three parts, the lower being the *Coralline Crag*, so called from the numerous remains of corals found throughout the bed; the next the *Red Crag*, distinguished by its deep ferrugineous stain; and the uppermost, the *Mammaliferous* or *Norwich Crag*, which is of more recent origin than the Red Crag, and contains bones of large mammalia, and occasionally fresh-water shells. All these beds are of limited extent, the Coralline Crag ranging over an area of about twenty miles long, and three or four broad, its total thickness averaging not more than twenty feet, while the Red Crag, although extending to double that thickness, is still small in every respect. The Mammaliferous Crag appears to be an estuary deposit.

At various places in the valley of the Thames, and on the banks of the Stour and Medway, fresh-water deposits have been found, some of which appear to correspond in age with the newer portions of the crag, while others are still more modern. In the valley of the Clyde, near Glasgow, extensive beds, of comparatively modern date, have been described under the name of '*Till*,' chiefly consisting of unstratified clay mixed irregularly with gravel; similar or contemporaneous beds have been found at Bridlington, on the Yorkshire coast, and at various other localities, where evidence of recent change of level has been sometimes also seen in the raised beaches and sub-marine forests.

The middle tertiaries form a much more decided group in various river basins on the Continent than they do in our own country. They occupy a considerable portion of the west of France, filling up the basins of the Loire and the Garonne; they fill up also a great part of the valley of the middle Rhine; they alone are to be met with in the whole of the great valley of Switzerland, between the Alps and the Jura chain; and they proceed towards the north-east from Switzerland, following the course and partly occupying the valley of the Danube. From point to point they may be traced spreading out into extensive series near Vienna and in Styria, and occurring again in the plains of Hungary; they are also found in Poland and Russia; they appear both in northern and southern Italy, and on the shores and islands of the Mediterranean; and they are probably represented in the neighbourhood of Lisbon, and in the south of Spain. They thus form a most extensive group indicating, with much distinctness, that many portions of what is now Europe were submerged during the middle tertiary period.

The newer tertiary period is not less amply represented in Europe than the middle one; but it is chiefly in South Italy, in the Morea, and in the islands of the Eastern Archipelago, that the more extensive beds must be sought for, although the valley of the Lower Rhine, near Bonn, and a portion of central France, besides a large district in southern Russia, also present important contemporaneous beds.

The newer tertiaries are not all of the same age, and the beds so called must have been in the course of formation for a very long period. Those in Italy admit of being subdivided into two groups, the older of which is called Sub-Apennine, and attains a great thickness near Parma. These beds consist for the most part of greyish, brown, or blue marls, containing calcareous matter, and overlaid by thick sandy beds. The Sicilian beds are distinctly newer than these, and are equally extensive, since in the south of Sicily hills, 2000 feet high, are formed entirely of the uppermost of them. Marls, with occasional limestone, form the great mass of the materials of these strata.

Fresh-water beds of the newer period are found at Œningen, on the Lake of Constance, consisting chiefly of fetid marlstones and limestones, and occupying depressions in the molasse. These beds are of great thickness, but small extent.

The newer Tertiary deposits of the Rhine and Nassau are remarkable for the presence of very extensive beds of lignite, so thick as to be worth working, although the coal is too earthy and imperfectly bitumenized to be a valuable fuel.

Other deposits of the same age are found occupying an extensive region in southern Russia, and well exhibited in the cliffs on the Sea of Azof. They consist of beds of white and yellow limestone, covered by sands and siliceous grits. Similar beds occur in the Crimea, and the neighbourhood of Odessa.

125 *The Tertiary Deposits of Asia and America.*—Till within a very few years nothing was known of the great extent of these formations, and they are not even yet described in such detail that we can speak with certainty as to their geological age. The western part of Asia, generally, seems to exhibit a great variety of volcanic phenomena of recent date, accompanied by a considerable extent of modern Tertiary deposits, chiefly lacustrine, and consisting of calcareous marls, and white limestone containing chalk. Some of these have been already alluded to, from their vicinity and resemblance to European tertiaries, as for example, the beds at Smyrna, and others on the shores of the Caspian. There are, however, others further east, which now require consideration.

In the western part of India, near Bombay, thick beds of Tertiary limestone have been found, chiefly near Cutch, which are covered by argillaceous grits, and belong probably to the older part of the Tertiary period. Similar beds have been described as occurring in the more central province of Mewar, and also at Delhi. Beyond this the Tertiary beds of the Sewâlik range commence.

The formations composing the Sewâlik or Sub-Himalayan hills, consist of beds of boulders or shingle, of sands hardened to every degree of consistency, of marly conglomerate, and of an infinite variety of clays. The strata dip towards the north, at angles varying from 15° to 35°, and the breadth of the inclined beds is from six to eight miles.

In a part of the Sewâlik district, west of the Jumna, there is an interminable series of clays and sandstones, the former being most abundant, and in the upper part of the series, there occurs a sandstone rock, generally soft, but often in hardened masses, owing apparently to the presence of organic bodies, chiefly bones. A very large and remarkable group of organic remains has been obtained from fragments embedded in this way in sandstone.

The Tertiary strata of the Sewâlik hills appear to have extended along the whole of northern India, north of the Ganges, and they occur also near Bombay, on the one side, and in the Birman empire, in the upper part of the drainage of the great Irawaddi river.

There is a deposit, in various parts of India, called *Kunkur*, which is very generally distributed, and appears not to be confined to one period, although certainly not very ancient. This deposit is especially abundant in the country running up from Gujerat to the north-east, towards Delhi, and appears covering hills two or three thousand feet above the sea.

Little is known of the existence of Tertiary beds in the great plains of Siberia and northern Asia, and we are equally without information concerning China, Chinese Tartary, and Japan. There are not known to be any well marked tertiaries of older date in the islands of the Eastern Archipelago.

North America presents considerable tertiary beds in Virginia, the two Carolinas, Georgia, and Alabama, chiefly belonging to the older part of the period, and others of newer date in other districts. In Virginia there are greenish sands, replaced to the south by white limestones, of no great thickness, nearly contemporaneous with our London clay, and these, after being traceable for several miles, are lost under newer deposits, of considerable thickness, consisting of clay and loam, alternating with quartzose sand and beds of pure silicious rock, full of interstices.

Over the series of older strata thus described there is found, occupying a wide horizontal range, a deposit of clay of the middle Tertiary period, spread over immense plains, but little above the level of the Atlantic. These are replaced, in Massachusetts, by white and green sands and conglomerate, resting on lignite. Upwards of ten thousand square miles of country are occupied by these deposits, while others of somewhat newer date occur at the mouth of the Potomac river in Maryland, and consist chiefly of clay and sand.

In South America, the rocks of the Tertiary period are more extensive and important than in any other part of the world, extending in an unbroken line from the great plain of the Amazons to the Straits of Magelhan, a distance in all amounting to 2,500 miles, while in some places they are not less than 800 miles broad. Throughout this vast tract three principal groups have been determined—the lowest consisting of sandstones and marly limestones covered with gypseous clay, which retains water on its surface and produces marshes; the middle, or 'Patagonian series,' as it has been called, larger in extent and nearly the same in mineral character, and the highest or newest deposit, the 'Pampas clay,' is a single bed, probably one of the largest ever yet formed on the earth, covering a space of 180,000 square miles, and throughout chiefly argillaceous. It is partly covered up by alluvial sands.

126 *The Newest Deposits of Gravel and Diluvium.*—The regularly stratified deposits are often seen to be more or less covered up and hidden by a mass of heterogeneous material, generally unstratified and deposited in irregular heaps, but almost always bearing marks of having been transported from a distance. The fragments of transported rock which make up this mass are called 'boulders,' or 'erratic blocks,' when of large size and angular, and are in this case rarely far removed from the parent rock; but they are more commonly smaller and rounded, as if they had been long rolled against one another at the bottom of water, and in this state, and especially when mingled with fine sand, they are called 'gravel.' Such material has often been conveyed from great distances, amounting sometimes to many hundred miles from the place whence the rocks which compose it were derived. The whole deposit when of this nature is not unfrequently called *diluvium*, or diluvial drift, while *alluvium*, on the other hand, is a term used in contradistinction to diluvium, and signifies the ordinary effects of fluviatile action.

The origin of gravel and diluvial drift is a subject which has long attracted the attention of geologists, and which is not yet clearly made out. The direction of the drift, which can be traced by following up the gravel to its source, varies very considerably in different districts, but it generally seems to have travelled from some mountain chain, with the elevation of which the existence of these singular heaps seems to have been connected.

Among the more remarkable and instructive illustrations of the phenomena of gravel, must be ranked the gravel hills in the south of Scandinavia, and the isolated patches in the plains of Northern Europe—the *escars*, or gravel hills of Ireland—the detritus of England, as traced from the Cumberland hills to the north, south, and east—the diluvial phenomena of Switzerland and Italy—the gravel of North America, and that of some part of the southern extremity of the New World.

Connected with gravel phenomena, there must also be considered the rubbed, grooved, and polished condition of the rocks on which this material has been heaped, as these appearances have been the groundwork of theories suggested, and require to be accounted for in the explanation of the phenomena.

The tertiary deposits in many parts of South America near the banks of the great rivers are not, however, of this nature, as in most cases they appear to consist of nothing more than the mud deposited at various points and over wide areas, which some mouths of the gigantic rivers of that country once traversed. The shifting of the actual river course, and its replacement by thick mud, is, in the case of all rivers possessed of deltas or depositing much mud, an event so much a matter of necessity, that we need not here allude further to it.

With regard to the gravel beds and erratic blocks of North Europe, they are chiefly grouped in elliptical areas, with the longer axis pointing to some part of the Scandinavian mountains. The larger blocks are generally near the surface. The blocks consist principally of granite, Syenite, porphyry, and hard limestone, and have been found in Poland and Russia as well as North Germany, reaching from the Ems and Weser to the Dwina, and even the Neva. In Scania they are however much more abundant, and the quantity of material greater, though the blocks are not larger.

The dispersion of blocks from the Cumberland hills is also remarkable, as the rocks themselves of which these mountains are composed are very distinct and peculiar, and very easily recognised. The granite of Ravenglass, on the western border of the region, has been drifted to the south across the sea, along the flat or hollow of Lancashire, west of the Penine chain, and over the plains of Cheshire and Shropshire towards the valley of the Severn. In this long course the quantity of pebbles and boulders is very considerable, and it is evident that the currents, whatever they were, which carried the boulders, respected the present levels of the country, for they have not once crossed the Penine chain to the eastward, nor penetrated far into the principality or the border districts, where the gravelly deposits have been derived from the neighbouring hills. From the eastern side of the Cumbrian mountains, the granites of Shap Fell and Carrock Fell have been transported northwards to Carlisle, southwards by Kendal and Kirkby Lonsdale to beyond Lancaster, eastwards over the vale of Eden, and up the Penine escarpment at Stain Moor above Brough. Having here mounted the summit, the boulders diverge to the east-by-north, east and south-east, cross many lower ridges, and sweep over the oolitic moors and the chalk wolds to the sea-side at Scarborough and Flamborough Head, a distance of 110 miles. In this course three ridges and two vales were crossed, but the present configuration of the ground has manifestly undergone no change, as the passage of the Penine chain is at only one point, and that the lowest, opening directly to the west.*

The phenomena of rubbed surfaces of rock beneath accumulations of gravel, and in the track of large blocks and considerable masses of diluvial material, are important as pointing to the probable origin of the accumulations themselves. The appearance is sometimes exactly that produced now by the action of a glacier moving along slowly, loaded with a heavy weight of transported matter, or else appears due in a similar way to the action of ice, which must in that case have drifted on the spot where we now find the gravel, when the level of the surrounding land was much below its present position. There can be little doubt that the transporting power of floating and drifted ice, as affording a ready means of removing large heaps of rock—as accounting for the deposit of these in one spot, far removed from the mountains whence they were derived, and as explaining the marks of mechanical pressure and rubbing met with in the vicinity of isolated large blocks, or considerable quantities of smaller ones—is a probable and satisfactory explanation of the phenomena of gravel.

Many of the limestones of various geological periods are remarkable for containing caverns, originally, perhaps, mere cracks in the strata, but since then worked into holes by the passage of water, or by other mechanical means. These have often served as the dens of wild animals; and, when afterwards silted up, and their floor covered with stalagmitic incrusta-

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* Phillips's *Treatise on Geology*, (Edinburgh, 1838,) p. 209.

tion, whatever remains these animals left have been accurately preserved, and may often be obtained for investigation. We learn in this way, that large hyænas and bears once roamed over the waste expanse of our own island and of Europe, and that these fierce carnivora were accompanied by a singular race of ruminants and pachyderms; among the former being large animals of the deer tribe and a gigantic ox, while the latter included the elephant, and a nearly allied genus, whose habits appear to have required the vicinity of extensive marshes.

It is, however, almost exclusively the remains of carnivora that are found in the caverns, which must in many cases have been the resort of successive generations of wild animals for a long series of years. The species of bear and hyæna, whose remains are chiefly abundant, were much larger and more powerful than any of those now living, and there are indications also of a very large feline animal (a tiger) existing contemporaneously with them.

The gravel in various parts both of England and elsewhere contains numerous fragments of the bones of the larger quadrupeds, once the inhabitants of this region. Among them may be enumerated the elephant, the rhinoceros, a hippopotamus, several large cervine animals, one of them remarkable for the enormous spread of its horns, and some large species of the *Bos*. All these were contemporaries, and living also at the same time were the wolf, the fox, the badger, the otter, and a number of species still remaining. Concerning the nature of the revolution which, extending over the whole of Northern Europe, destroyed entirely all vestiges of the larger mammalia as indigenous species, allowing the smaller ones to remain, it is not easy to decide in the present state of our knowledge.

In other countries, as in Asia, America, New Holland, and New Zealand, there are similar proofs of the former existence of gigantic animals of analogous species to those which compose the existing faunas, and we everywhere find marks of extensive changes produced on the surface indicated by the presence of numerous fragments of rock, transported from a great distance, and more or less evenly spread over the face of the country.

The only ultimate cause that can be assumed, with any degree of probability, as accounting for these phenomena, is the slow and successive elevation of large tracts of land at certain intervals. It is not unlikely that such elevation, even if in some places permanent, might be accompanied by a partial sinking, and there is evidence of recent elevation and also of depression to a very great extent over most parts of the whole world. Such evidence is seen in ancient sea beaches, and in deposits once formed quietly at the bottom of the sea near coast lines, but now raised many feet, and sometimes many hundred feet above the existing sea level; while not far off the presence of decayed forests running out towards the sea at levels below that of high water, affords not less satisfactory proof of partial depression.

Thus we have seen that the structure of the Earth's crust, considered simply in a mechanical sense, offers a vast variety of facts, which it is not easy at once to explain; that, however, all these facts point to some regular plan and system in the elaboration of the existing surface; and that the successive deposits which may be traced have been altered and disturbed by frequent upheavals. These general results of the investigations of geologists require, however, to be considered and compared with reference to the organized beings which also greatly modify the Earth's surface. and whose conditions of existence we next proceed to discuss.

PART III.

ORGANIZATION.

CHAPTER X.

THE DISTRIBUTION OF VEGETABLES IN SPACE.

§ 127. The meaning and nature of organization, and especially of vegetable life. — 128. Natural arrangement and classification of plants. — 129. Influence of climate on vegetation. — 130. Influence of soil on vegetation. — 131. General range of plants in various countries at moderate elevations. — 132. The botanical regions. — 133. Distribution of plants in vertical space. — 134. Range of cultivated plants. — 135. General considerations of the distribution of plants in distant botanical centres.

THE Meaning and Nature of Organization, and especially of Vegetable Life.—The vegetable world presents us with some of the most readily understood of those forms of matter which are endowed with vitality, being provided with organs enabling them to form new and peculiar combinations of various elementary substances. In other words, we have in this department of natural science a new force introduced, modifying the action and altering the results of other forces—a body not only capable of selecting and separating the various material elements, and bringing them into new combinations, but also of reproducing another body, which, though at first different in many respects, will, after passing through certain transformations and metamorphoses, repeat the individual and continue the race.

The basis of structure of all the various and dissimilar vegetables is, however, the same—it is a little closed vesicle composed of a membrane, usually transparent and colourless. The cell-wall consists of carbon, hydrogen, and oxygen, while a semi-fluid investing substance contains also nitrogen. These elementary substances, in various proportions, make up the mass of all vegetation; and the cells in the course of their development becoming crowded closely together, form into three principal tissues, according to the shapes of the cells, and their importance to the life of the plant. We may indeed regard the cell as a little independent organized body living for itself alone. It imbibes fluid nutriment from the surrounding parts, out of which, by chemical processes, which are constantly in action in the interior of the cell, it forms new substances, which are partly applied to the nutrition and growth of its walls, partly laid up in store for future acquirements, partly again expelled as useless, and to make room for the entrance of new matters. In this constant play of absorption and excretion, of chemical formation, transformation, and decomposition of substances, especially consists the life of the cell, and—since the plant is nothing but a sum of many cells united into a definite shape—also the life of the whole plant.*

Since, then, every plant in its course of formation, and every undeveloped part of a plant, consists of these cells, which in their growth, and by pressure against each other, become six-sided, radiated, cylindrical, spindle-shaped, or

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* Schleiden's *Plant*, translated by Henfrey, p. 45.

even filamentary, and which sometimes multiply so rapidly, that in one fungus, (*Bovista gigantea,*) 20,000 new cells are formed every minute, we may well understand the necessity of making out something of their structure, mode of growth, and natural relations. By one modification of the cells is formed the external layer of the plant or epidermis, a membrane which appears continuous, and which, as *bark*, is known to every one. Another modification produces tubular channels, which appear to the naked eye as fibres, but which allow of the passage of the fluid contents or sap circulating through the plant, or else serve as air vessels; while a third continues the development of these vascular bundles, and at length produces what is called *wood.* Those plants, and parts of plants, which consist neither of bark nor wood, exhibit the cells either in their simple state or as vascular bundles, so that these three conditions may be considered as the fundamental ones, and as involving all that need be at first regarded.

The contents of the cells of plants are, however, also very important, and may be divided into two groups—those soluble and insoluble in water. The former include albumen, gum, sugar, and the agreeable acids of fruits, such as malic and citric acids. The latter are chiefly the fat oils, such as are found in the kernel of the almond and the fruit of the olive, and the aromatic oils which characterise many plants. Of all these various contents, however, the starch found in the cells, under certain circumstances, and composing a large portion of the nutrient matter of plants, is the most important. It occurs in every part of every plant, but only the roots, tubers, seeds, fruits, and more rarely (as in the sago palm) the pith, afford sufficient to serve as food, or repay the trouble of separating it.

Such being the general condition of the matter of which plants are made up, it is still only when endowed with vitality that they exhibit the properties peculiar to organization. The cell-formation, the first result of life, changes that which was merely a mineral into an organized body, and then all the different plants are distinguished from one another by the shape or plan according to which the cells are united together. The form, therefore, and modifications of form, as they develop the system in plants, are matters without a strict knowledge of which the idea of the vegetable kingdom cannot be conceived, and in order to assist in this conception, it is well to describe the language of naturalists in this department of science with reference to a single plant.

A plant, then, may be said to consist of the following parts, although it must be remembered that some of them are absent, and others greatly modified in particular natural groups. There is a continuous principal trunk or *stem*, with various lateral appendages, of which three kinds may be traced, namely, the *root*, the *leaves*, and the *buds;* but the latter being, in fact, repetitions of the whole plant, except that they are not free at the lower extremity, and the roots agreeing perfectly, in all their characters, with the free extremity of the plant, we have the plant really made up of a stem or axis, terminating downwards in roots and rootlets, which attach it to some solid support, and upwards in a *seed-bud,* whence the original plant is repeated, and leaves, which vary greatly in their form and nature, since amongst them, and belonging to them, must be ranked all the beautiful flowers and delicious fruits presented by the vegetable kingdom. Different in external appearance as these are, their true character no longer admits of a doubt, and the change that takes place belongs to development, according to well marked and invariable laws. According to the kind and degree of development that is natural to plants is their ultimate and characteristic form, and specific definition.

128 *Natural Arrangement or Classification of Plants.*—The first beginnings of vegetation are seen when a green film covers old damp walls, or is deposited on the sides of a glass, in which soft water has stood for several days in summer. These consist of the simple cell, vegetating as an independent plant, and are succeeded in organization by the confervæ or mould, where the cells are arranged in lines and filaments. Then come those long,

thin, and lettuce-like leaves, sometimes green, sometimes red, often found on the coast, and afterwards the vast tribe of *Lichens* and *Fungi*, which with the sea weeds (*Algæ*), form the three groups composing one large class of plants. In the first mentioned tribes there are no definite organs, but in these latter there are cells separated from the rest, and destined to the production of reproductive cells; but it is important to remember that, in all plants, the same organ may serve the most different vital offices in different plants, and the same vital process may belong to the leaf in one plant, to the stem in the other—except, indeed, the organs of reproduction, which are not applied to any other use.

In the higher sea-weeds and lichens, the forms which in the Fungi (and also in those lichens covering walls, stones, and palings, with a whitish-grey or yellow scurf) are very indeterminate, put on a more definite and regular character, exhibiting constant shapes, which resemble stems and leaves, though they have not the same uses, nor the same relation to their detailed structure. All these plants, however, present this one great peculiarity, that in none of them is there, properly speaking, either stem or leaf, and they are consequently flowerless, and have no visible organs of fructification, in the usual meaning of the term. They thus form a separate natural group, which is associated by very close natural resemblances with another group, of which the Mosses, Ferns, and Club Mosses, are well known examples. In all these, there can be distinguished a distinct stem, with leaves, but a peculiar series of gradations is presented in the formation of the reproductive cells, which first come into more intimate connexion with the leaf, and at last assert so strongly their claim to definite foliaceous organs, that they lose all resemblance to the other leaves. Thus, in the Mosses and Ferns, there is a peculiar approximation in form to the structure of the reproductive organs of more highly organized plants, while in the Club Mosses, the resemblance is even greater, and the analogies are more real. All the various natural groups above referred to are described by botanists under the general name of CRYPTOGAMIA, and the second group are also called *Acotyledons*, owing to the plant not growing from a seed, which contains nourishment for the young individual during the earliest stage of its existence, although in some respects resembling plants of higher and more complicated organization. In all other plants the stem and leaf are the elementary organs, but definite leaves are transformed so as to form reproductive cells, and these are therefore sometimes called *sexual plants*, to distinguish them from the Cryptogamous tribe.

The sexual plants are again subdivided, one group exhibiting a very simple inflorescence—indeed, no flower in the ordinary sense—and presenting the seed naked and undefended. The whole fir tribe, the misletoe, and a family of tropical plants (the *Cycadaceæ*) are of this kind, and offer a striking contrast to the other plants where the inflorescence is remarkable and characteristic. The phanerogamous plants are therefore either *Gymnosperms* (naked-seeded) or *Angiosperms* (covered-seeded); and the latter are either developed from a bulb or single-lobed seed, as the palms and grasses, and are called *Monocotyledons* (single seed-lobed), or from a double seed, like the bean, thence called *Dicotyledons* (double seed-lobed). The plants of the two series not only differ essentially in their apparently unimportant characters, but in all the rest of their organization; and are so strikingly distinct in their external appearance, that a little practice enables the eye to recognise them at a glance. Thus the first or monocotyledons generally have the fibre-like wood-bundles scattered throughout the stem, as in the maize, while the second has a closed firm circle of wood, like the willow; in the leaves of the first the veins are usually parallel, as in the grasses, but in the others they ramify like the branches of a tree, and form an elegant net work on the surface of the leaf, as in the lime; and finally the number three prevails in the floral arrangements of the first, as in the tulip, while the number five is that found characterizing the other, as in the primrose. The two series proceed parallel with each other in respect of inflorescence, from the simple to the more complicated forms, so that in the highest stage, where a number of separate flowers are united into one definite whole, arranged according to a marked type and defined with circlets of leaves, we find on the one side the grasses and on the other the so called *Compositæ*, of which the daisy, dandelion, thistle, &c., are well known examples, holding side by side the highest station in existing vegetation.

Thus, then, we find all the plants brought within range of description, by referring to these important, because natural, characteristics, and it may be worth while here to recal the principal points, and express in a tabular form the outline of the classification as a matter to which we shall frequently have occasion to refer.

Cryptogamia.

1. Thallophytes. (*Confervæ, Fungi, Lichenes, Algæ.*) Stemless, and often without leaves or roots, growing in a centrifugal manner, and capable of undergoing modifications in the individual cells.
2. Acotyledons. (*Liver-worts, Mosses, Ferns, Equisetaceæ, Club-mosses, and Rhizocarps.*) Having stems, vascular bundles, all developed at the same time, embryo a simple cell or congeries of cells, growth simultaneously upwards and downwards from the central axis or stem, no visible floral development.
3. Angiosperms. (*Coniferæ, Cycadeaceæ, Loranthaceæ.*) Inflorescence very simple, not presenting a true flower, seed-bud and seed naked.

Phanerogamia.

4. Monocotyledons, also called Endogens. Having one seed-lobe, which forms one small leaf in the embryo state, the fresh leaves springing from the centre, and the footstalks of the old leaves forming the outside of the stem; the vascular bundles definite, and converging towards the interior; not having true wood; illustrated by the palms and grasses—all the arrangements having reference to the number three and its multiples.
5. Dicotyledons, also called Exogens. Increasing by successive coats from without, the growth of each year forming a concentric circle of wood round the central pith; having two lobes in the seed, symmetrically arranged, and appearing as two small leaves above the ground when the plant first grows; vascular bundles indefinite; the floral and other arrangements governed by the number five. Most of the common forest-trees of temperate climates, as the oak, beech, &c., are examples of this group.

129 *Influence of Climate on Vegetation.*—Plants being thus very variously constituted, and offering so many varieties of structure, are greatly influenced by various causes, of which climate and soil are the most direct and important. Thus in tropical climates monocotyledonous plants abound, and in temperate regions dicotyledonous, while in polar or extremely cold countries, the vegetation is chiefly cryptogamic. On the other hand, certain tribes of plants are strictly confined to particular local conditions, which, at least to some extent, are connected with the soil, directly as well as indirectly.

We have already, in speaking of the distribution of temperature on the globe, explained those causes on which climate depends, and the vast difference in climate that may exist in places having the same latitude, but different longitude; in others, having the same mean annual temperature, but different summer and winter heats; and in others, having the same extreme limits of temperature, but not on the same isothermal. Vegetation is greatly influenced by almost every distinct change of climate, although individual plants will adapt themselves permanently to considerable ranges of heat and cold.

With regard to the extreme limits of temperature at which vegetable organization can exist, we may say, that although seeds will not germinate at a temperature below the freezing point of water, (according to Göppert's recent observations, 39° Fah. is the limit,) still even the extreme cold required to freeze quicksilver does not destroy their vitality. So also, on the other hand, no seed will germinate in water whose temperature is 122° F., and at the heat of 144° in vapour, and 167° in dry air the vitality of corn is destroyed. It is indeed probable that a long continuance at much less extreme temperature would be absolutely destructive, since in the case of grain an exposure to 95° F. for three days has been effectual in preventing subsequent growth.

It has been observed generally that the mean temperatures of different seasons and single months form the best guides for purposes of botanical geography, since, if the isothermal lines only are attended to, the most extreme dissimilarity may exist in real climate. In those places which have the same isotheral lines, (equal mean summer temperature,) and in which the maxima of heat for certain limited periods are nearly the same, there is a sufficient resemblance to allow of the growth of similar plants, although in the one place the winter may be mild, and in the other very severe.

It is well known that the leaves and flowers of the same plant are unfolded at different periods of the year; earlier in the warmer regions, later in the colder. M. G. de. St. Hilaire once observed the peach trees at Brest without leaves or blossoms on 1st of April; on the 8th he found them in full bloom at Lisbon; on the 25th, at Madeira, the fruit had set; and on the 29th he got ripe peaches at Teneriffe. Numerous other examples might be quoted, the general result being that for each degree that the station of a plant is nearer the pole, the time of flowering is delayed almost four days, but there are many causes which greatly modify this law, and it may be otherwise and more accurately expressed by saying, that vegetation is retarded, on an average, three days if the temperature be diminished one degree of Fahrenheit, although, after all, such calculations have no very sound basis. It requires light and the action of the chemical rays of the sun to stimulate plants to activity, and perhaps heat may be a much less important element than has often been supposed.

Climate alters and is combined with a change in the condition and pressure of the atmosphere as we ascend from plains towards table-land and the higher portions of mountain-chains. This is seen equally well in whatever part of the world the investigation is made, and modifies very greatly both the present and past distribution of vegetables on the Earth. Thus, at the foot of a mountain, the plants of the plain appear, but they gradually disappear as we ascend, and a traveller familiar with the vegetation, or *flora*, of an arctic or temperate climate, will find, in ascending high mountains within the tropics, that he sees first one and then another group of familiar forms prevailing over the tropical forms of vegetation that he has left in the plains. After a time, even the trees cease to grow to their full height, bushes being the largest plants, and, at length, as he approaches the limit of perpetual snow, the bushes give place to herbs, these to lichens, and but a few of the forms of plants of the arctic zone are missing, while even the same species re-appear after having been lost throughout the whole space between the arctic regions and the summits of these mountains.

There is, therefore, a certain parallelism between the distribution of vegetation from the level of the sea to the limit of perpetual snow, and that from the equator to the poles, although the gradual change of vegetation takes place much more slowly towards the poles than with increasing altitude. With our present knowledge it is now no longer difficult to perceive that this parallelism exactly agrees with that which we find between the gradual decrease of heat from the equator to the poles, and that from the plain to the limit of perpetual snow.*

It is extremely difficult even to imagine any hypothesis which shall explain the true influence of climate on vegetation, for we often find plants capable of undergoing great changes in temperature and even in all other constituents of climate without injury, and yet naturally limited in extent within very narrow bounds. On the other hand, however, we find forest trees and natural tribes of well known plants altering their external character and form to a very great extent when exposed to a change of climate, either

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* Meyen's *Botanical Geography*. Translation published by the Ray Society, p. 26.

by removal to a different latitude, or by being transplanted to more or less considerable elevations above the sea level.

As an example of another kind we may take the case of barley, which is cultivated from the extreme limits of culture in Lapland to the heights immediately beneath the equator, although it is only within a very narrow zone that it apparently flourishes under natural conditions. It has been found by some curious experiments that in several places under latitudes varying as much as forty degrees, the actual number of days between planting and reaping multiplied by the mean temperature is nearly the same, so that to define accurately the conditions of temperature required to maintain any plant in a flourishing condition we must state within what limits its period of vegetation may vary, and what quantity of heat it requires.

The great importance of considering the extremes of temperature in speaking of climate is, however, best illustrated in the case of the vine, which will indeed grow, and, in some seasons, produce eatable fruit in many districts beyond certain well defined limits within which drinkable wines are grown to profit. For this latter purpose a mean annual temperature of more than 49° Fah. is sufficient, provided the mean winter temperature is above 32°.8 Fah., and the mean summer temperature at least 64°.4. Thus, at Bordeaux, (latitude 44° 50′,) the mean temperature of the year is 56°.8, of winter 43°.2, and of summer 71°. On the Baltic, (latitude 52½°) at a spot somewhat beyond the extreme verge of the wine-drinking countries, the corresponding figures are 47°.5, 30°.8, and 63°.7 respectively, and here wine is produced, but can hardly be called drinkable. On the east coast of Ireland, in latitude 55°, the myrtle flourishes as luxuriantly as in Portugal, but the summer temperature being low, the vine will very rarely ripen its fruit in the open air, for the mean temperature for the month of August being only 60°.8 Fah., the proper summer average is not approached, and the mildness of winter, which raises the isothermal, cannot make the required difference. Thus, the culture of the vine and the profitable limits of other plants useful to man, depend more on the isotheral than the isothermal line, and are little affected by great cold occurring in winter.

130 *Influence of Soil on Vegetation.*—Plants are generally attached to the earth mechanically, and derive very important inorganic substances from the soil in which they grow. Many, however, can exist permanently in water, while some few seem to require nothing more than they can obtain directly from the air, and others derive support only indirectly from the soil, being attached as parasites to other plants.

Almost all soils, even fine quartzose sands, the most barren of all, contain some soluble matter which plants can avail themselves of, and if we remove any plant to matter perfectly insoluble and water it with distilled water, it can never attain to perfect development, although with carbonic acid gas and water it will continue to live. Water is thus absolutely essential, and carbonic acid not less so, to the existence and reproduction of all vegetable matter, but much more than this is generally required, and it becomes important to know how far the presence or absence of particular minerals, the nature of the materials of which a soil is principally made up, or the mechanical condition of such materials affect the capacity of the soil for receiving and nourishing certain plants or natural groups of plants.

From the different habits already alluded to it will readily be seen that a division into aquatic, land, and parasitic plants, includes almost all the various kinds we are likely to meet with.

The first class includes many groups, and with them may be properly associated shore plants, amphibious and inundated plants, and some others; while the third or last class includes those only which are limited, so far as their habitat is concerned, to other trees and vegetables. But it is with the second class that we have now to deal, and these also are much subdivided, as we have sand plants, limestone plants, clay plants, gypsum plants, turf plants, bog plants, and marsh plants. We may also consider in reference to this subject the mechanical condition of the soil and subsoil, some plants growing on hard rock; others on fragmentary or broken rock, boulders, or gravel; others on material in finer subdivision or sand; and others again on tough argillaceous rock; while, again, there are whole tribes of plants which seem to have especial reference to cultivation, becoming so far modified by artificial culture that their true habits are rarely now to be recognised. It will be convenient to follow the arrangement of Dr. Meyen (see *Geography of Plants* before quoted) in this part of our subject.*

Sand plants, or flint plants, are of peculiar character in all parts of the Earth, and the greatest number of them are probably grasses. Amongst them are a Carex (*C. arenaria*), an Arundo (*A. arenaria*), several species of Tussilago and Potentilla, and several other plants usually found in sandy plains, while one (*Elymus arenarius*) grows naturally and freely in shifting sand hills on the sea coast, and is often used with great advantage to bind loose sand, and prevent its being drifted by the wind when no mechanical contrivance will serve and no other plant will grow upon it. Besides these there are some plants confined to river sand.

There are plants which are found almost exclusively in rocks, and others again are more common on loose stones, amongst the former of which a great number of Cacti and other succulent plants in the tropics may be mentioned, together with the greater number of ferns, lichens, and mosses. These are found indifferently on quartz and calcareous rock, but particular species are limited more closely in geological position.

Gravel plants have been considered as chiefly growing on the detritus of mountains, such as *Saxifraga rivularis*, *Ranuncula alpestris*, and *R. glacialis*, and some species of *Sida* have been described, of remarkable beauty, growing on a white trachytic sand on extensive tracts in the plateaux of Peru, at an elevation of from fourteen to sixteen thousand feet.

Plants growing on calcareous rocks, whether chalk or limestone, form another group, of which the family *Orchideæ* presents many species. Calcareous mountains exhibit many peculiarities in their vegetation, having for the most part few woods, but generally rather a shrubby and bushy vegetation, and, therefore, they possess a number of small plants which grow in the shade of these bushes. The chalk of our own island is well known as growing a short but sweet herbage, and on the ridges of the hills the yew and some few other coniferous trees grow to large size. In addition to the plants growing on the calcareous rocks, some are found also where gypsum forms the subsoil, but this is by no means a common condition in nature. The presence of magnesia in rocks is generally unfavourable to the growth of plants, and the rocks that are very hard and not readily decomposed or disintegrated by atmospheric influence are also usually barren.

Mixtures of soils are often found to be most favourable for the growth of those classes of plants that naturally abound on the mineral that preponderates, but it must not be forgotten that even those plants which peculiarly belong to a soil, appear also very frequently elsewhere; and it has even been observed, that some which have undoubted preference for a soil of a particular nature have a much wider circle of distribution than others which grow in common mould.

Other mixtures, such as those which result in the formation of bog-earth and turf, have a peculiar vegetation, seen in those countries where turf-moors, bogs, and marshes are frequent and extensive. The species which grow on turf are distinguished by growing socially and by an excessive development of root. The *Sphagna* is an example of this, and is a plant which rarely allows any others to appear where it has taken up its abode. Bog plants grow on very wet soil, and as bogs are very frequent in northern

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* Meyen's *Botanical Geography, ante cit.*, p. 46 *et passim.*

countries and in the higher parts of mountains, such plants are found on the Alps, the Harz mountains, the mountains of Silesia, the plateaux of the Andes, and in Ireland. These, however, and turf plants are often mixed, as, in fact, a small addition of moisture turns a turf moor into a bog, and a still further addition to a marsh, but as marshes often contain sheets of water besides being permanently softer than bogs, they include also some aquatic plants and some peculiar to themselves. It is evident in all these cases that the qualities of the soil have in many important respects a decided influence on the presence of certain plants and on their abundant increase.

It is a singular fact, that a large number of plants seem to have attached themselves to civilized man, since they follow his footsteps as he advances, and thus appear to exhibit a kind of domestication. The higher and more stimulating quality of the soils used for the cultivation of the food plants is no doubt often the reason of this, but there are also others, and a number of species have been grouped by Schouw, one of the most eminent botanists in reference to the geography of plants, into wall-plants, ruin-plants, roof-plants, flank-plants, and rubbish-plants. These possess habits which are at once understood by their names, and in most cases show a decided preference for artificial over natural conditions of existence.

Certain species also appear in fixed and singularly remarkable situations, as for instance, there is an extremely pretty fungus, which is found on and appears absolutely limited to wine casks. There is also one (a Conferva) which grows on window panes, and another on paper. These habitats are remarkable as being purely artificial, and not presenting any very analogous substance in nature.

131 *General Range of Plants in various Countries at moderate Elevations.*—However clear it may appear that plants are greatly affected by soil, situation, and culture, so that while some have naturally a wide range, others are limited in this respect, from causes easily understood, it is yet equally clear, that there are other natural limits of distribution which it now becomes necessary to treat of. There are in this matter two very different classes of facts to be considered. The Heath plants, for example, *occur* on dry, sunny, sandy plains; they *extend* from the Cape of Good Hope through Africa, Europe, and Northern Asia, to the extreme limits of vegetation in Scandinavia and Siberia; these plants are *distributed* in this great region in such a manner that South Africa has a vast number of distinct species, of which, however, never more than a few individuals grow side by side, while, towards the north, the number of species suddenly diminishes in an important degree, the number of individuals increasing, till at last in the north of Europe a single species (the common Heather) overspreads whole countries in millions of single individuals. The range of distribution, or the area of a plant, includes all those localities in which plants freely grow, the expression 'natural habitat' denoting the particular station or stations to which it has been appointed by nature.

There are three ways in which we may speak of this area—namely, in latitude or distance from the equator towards the poles—in longitude or distance on a line parallel to the equator—and in vertical distance from the sea level. The two former may be called 'distribution in horizontal space'—and the latter 'distribution in vertical space.' There is also another distribution determined by the examination of the fossil remains of vegetables in various rocks, which as it appears to present something like analogous conditions, is now known as 'distribution in time.' In the present section we have to treat of distribution in horizontal space.

The distribution of plants is chiefly regulated by that of heat on various parts of the Earth's surface; and as this, again, has a certain relation to the parallels of latitude, it follows that the distribution is according to latitude principally, the longitudinal extent of the area being much less important.

The area of a plant, with reference to its extent in latitude, is called its 'zone of latitude,' or more simply 'zone,' and it is called the 'region,' when vertical range is referred to. The term zone of longitude is applied, though more rarely, to the horizontal range of plants in districts within similar limits of longitude.

The zone of every plant has a polar and equatorial limit beyond which the plant does not appear, but those plants whose polar limits extend to extreme latitudes are exceptions to this, as well as those which cross the equator, and enter the opposite hemisphere. The former are generally called polar or arctic plants, and the latter tropical plants, but this is not quite accurate, as an arctic plant may appear within the arctic zone without ascending to the highest latitudes. Similar examples might be given of tropical plants which do not reach the equator.

There are many conditions, some of which we have already adverted to, which modify and interrupt the range of particular species of plants. Thus, for example, if a plant require a certain degree of heat, and its presence chiefly depends on this, it may appear in all those places which have the same mean annual temperature, and thus exhibit a greatly interrupted range, especially when we combine vertical with horizontal distribution. The primroses, the anemones, and the gentians, of the plains of northern Europe, re-appear in this way at a certain elevation in the Swiss Alps, while *Salsola kali*, having an extraordinary and peculiar relation to the sea coast, has an almost uninterrupted range on the shores of most parts of the world.

It is clear, also, that there is an artificial, as well as a natural, range of plants, for man is enabled to transplant many, as, for instance, the cereals and the vine, so as to have corn in almost every country, while the grape, indigenous only within narrow limits, is now introduced and is cultivated to advantage in South Africa, Australia, the islands of the Eastern Achipelago, and many parts of America, on the Pacific as well as the Atlantic side. Many plants seem to grow with much more than natural luxuriance when introduced into new countries.

Generally it is found that plants with a naturally wide range may be extended much farther artificially, while plants of limited area are generally spread with difficulty, and we may lay it down as a rule, that the range of plants is wider the lower the degree of their development. Thus, the Cryptogamiæ—especially the lichens and mosses,—and probably the Algæ, are distributed uninterruptedly from one end of the Earth to the other, and of one hundred and sixty-seven plants, common to Europe and Australia, as many as one hundred and twenty-two are Acotyledons, thirty only being Monocotyledons, and fifteen Dicotyledons. On the other hand, some plants have a range as remarkably limited, being confined to an island or a mountain.

Plants vary so much in the extent of their range, that general rules can scarcely be laid down concerning them, but it has been supposed by Schouw, that in the temperate zone of the northern hemisphere, a distance of 10°—15° is the most common breadth of the area of a plant, while the extremes do not extend more than five degrees as a minimum and thirty as a maximum.

The longitudinal extent of a zone is often much greater, since there are some plants which range as a belt round the globe. There are, however, cases of very limited range in this direction, generally caused by the existence of some natural obstacle, as a broad expanse of water, or a lofty mountain ridge.

The subject of the distribution of plants may be divided into two perfectly distinct branches, one of which treats of the distribution of the forms which point out the groups of plants, while the other does not inquire concerning the absolute predominance of any particular group or type, but considers the relative proportions founded on actual numbers, which any given group, by its number of species, bears either to the whole mass of known plants, or to the number of species of other groups. The former gives what may be called the Physiognomy of plants, since in it the general aspect is regarded, while the other presents the true Statistics of plants. As an example, it is well known that a particular group of plants, such as the ferns, may determine the natural character or floral physiognomy of a country without therefore being predominant by the number of its species, because, although in the same country, some other plants, such as the *Compositæ*, may exceed the ferns in the actual proportion they bear to the sum of all the phœnogamous plants, yet a single species of fern may cover ten times more ground than all the Compositæ together. The ferns here preponderate by the mass of individuals, not by the number of species.

It is at any rate a fact, and a very important one, that plants are distributed over the Earth's surface according to certain laws, but of the true nature of these we are not perfectly acquainted, for although we know some of the external causes which place the more developed and nobler forms of vegetation in the hot zones, we know of no cause why the same species of plants are not always produced under similar conditions of climate. Thus, the singular group of the *Cactaceæ* is properly peculiar to the torrid and subtropical zones of America, two species only having been met with in Asia, and none in Africa. But the form of Cactus has its representative in the Old World, for we have on both sides *Euphorbiæ*, which we should certainly consider Cacti, if we were ignorant of their organs of fructification. It is equally inexplicable why the Old World should possess abundance of heaths (*Ericæ*), while only a representative form (not a true heath) comes in their place in America; but these and other remarkable facts agree in showing that the greater number of families of plants are distributed over the whole globe, individual representatives of the groups appearing wherever a fertile soil is exposed to light and air.

In the distribution of plants, it has also been observed, that the species of genera, as well as the genera of families, proceed sometimes from a point, and range themselves round it in concentric circles, or spread from it like rays in various directions, while in other and more common cases, they are arranged in belts. Occasionally these methods are modified by the social or isolated habit of the plant, which is a very important circumstance in its distribution.

Genera, as well as families, attain their maximum in some one place on the Earth, and when in addition to this the number of individuals in which the genus or family grow is sufficient to influence the physiognomy of the flora, it has been found convenient to give a special name, generally formed from that of the country or zone. The Palms and others are thus almost exclusively confined to the torrid zone, and are regarded there as characteristic, although species extend far to the north and south of the two tropics.

When a family of plants predominates in any zone, either by a number of individuals or species, and in another zone there are only a few or single forms of it, the family is said to be represented by the few species, and these are then called the representatives of the family. Thus, the Heaths of the Old World have their maximum in South Africa, but the beautiful shrubby forms abundant at the Cape of Good Hope are represented in the south of Europe by one species (*E. arborea.*) So the Acaciæ characterise New Holland, but one species (*A. heterophylla*) is the representative of the family in the Sandwich Islands, and in the form and growth of its leaves seems even to connect in the northern hemisphere two forms of prevalent vegetation in Australia.

If we consider the general features of the vegetation spread over the globe, or the different impressions which, at different places, it makes upon us, we shall soon remark certain principal groups, which are more or less clearly separated from the surrounding plants. These groups, which are distinguished by their peculiar physiognomy, sometimes agree also in artificial characters, and form certain genera and families, but sometimes it is the whole vegetation of the district which has received a peculiar character from the arrangement or grouping of the different forms of its plants. If we were to classify the whole mass of vegetation according to the peculiarities in physiognomy which it presents, the classification must be twofold, both geographical and botanical. When the geographical principle is taken, we may divide the vegetation according to the countries, or larger tracts, in which it is found, and call such divisions 'Floras,' which are further designated by the names of the countries, but such divisions may also be called 'regions,' or phyto-geographical kingdoms. The whole surface of the globe has been mapped out into such divisions, which we now proceed to enumerate.

132 *The Botanical Regions.*—Two eminent authors have suggested divisions of this kind. The first is that of M. de Candolle, with reference to natural stations, and the other by Professor Schouw, who has taken the most remarkable features of the vegetation of geographically marked districts. We quote the tables as given by Professor Balfour, in his *Manual of Botany*, not long since published:—

PLANTS AS GROUPED ACCORDING TO THEIR NATURAL STATIONS.

A. *Plants growing in Water, whether Salt or Fresh.*

1. Marine plants, such as Sea-weeds, Lavers, &c., which are either buried in the ocean, or float on its surface; also such plants as *Ruppia* and *Zostera*. In the Sargasso Sea there are floating meadows of *Sargassum bacciferum*, gulf weed. This sea extends from 22° to 36° north latitude, and from 25° to 45° west longitude from Greenwich, an area of 40,000 square miles.

2. Maritime or saline plants. These are plants which grow on the border of the sea or of salt lakes, and require salt for nourishment, as *Salicornia*, glasswort, *Salsola*, salt wort, *Anabasis*. Such plants are often called Halophytes (sea plants). Under this head may be included littoral and shore plants, such as *Armeria*, sea pink, *Glaux*, and *Samolus*.

3. Aquatic plants, growing in fresh water, either stagnant or running; as *Sagittaria*, arrow head, *Nymphæa*, water lily, *Potamogeton*, pondweed, *Subularia*, awlwort, *Utricularia*, bladderwort, *Stratiotes*, water-soldier, *Lemna*, duck weed, *Pistia*, *Confervæ*, *Oscillatoriæ*, and *Ranunculus fluviatilis*. Some of these root in the soil, and appear above the surface of the water; others root in the soil and remain submerged; while a few swim freely on the surface without rooting below.

4. Amphibious plants, living in ground which is generally submerged, but occasionally dry, as *Ranunculus aquatilis* and *sceleratus*, *Polygonum amphibium*, *Nasturtium amphibium*. The form of the plants varies according to the degree of moisture. Some of these, as *Limosella aquatica* grow in places which are inundated at certain periods of the year; others, such as *Rhizophoras* (mangroves) and *Avicennias*, form forests at the mouths of muddy rivers in tropical countries.

B. *Land Plants which root in the Earth and grow in the Atmosphere.*

5. Sand plants; as *Carex arenaria*, *Ammophila arenaria*, *Elymus arenarius*, and *Calamagrostis arenaria*, which tend to fix the loose sand, *Plantago arenaria*, *Herniaria glabra*, *Sedum acre*.

6. Chalk plants; plants growing in calcareous soils, as some species of *Ophrys*, *Orchis*, and *Cypripedium*.

7. Meadow and pasture plants; as some species of *Lotus*, bird's-foot trefoil, a great number of grasses and trefoils, the daisy, dandelion, and butter-cups.

8. Plants found in cultivated ground. In this division are included many plants which have been introduced by man along with grain, as *Centaurea cyanus*, corn bluebottle, *Sinapis arvensis*, common wild mustard, *Agrostemma*, corn-cockle, several species of *Veronica* and *Euphorbia*, *Lolium temulentum*, *Convolvulus arvensis*, *Cichorium intybus*, also plants growing in fallow ground, as *Rumex acetosella*, *Carduus nutans*, *Echium vulgare*, *Artemisia campestris*, and *Androsace septentrionalis*. In this division, garden weeds are included, such as groundsel, chickweed, *Lamium amplexicaule*, *Chenopodium vulgare*, and *viride*.

9. Rock or wall plants; Saxifrages, Wall flower, *Linaria cymbalaria*, *Draba muralis*, species of *Sisymbrium* and *Sedum*, *Asplenium*, *Ruta muraria*, and some lichens and mosses.

10. Plants found on rubbish heaps, especially connected with old buildings. Some

of these seem to select the habitations of man and animals on account of certain nitrogenous and inorganic matters, which enter into their composition. Among them may be noticed, Nettles, Pellitory, Docks, Borage, Henbane, *Xanthium.* Here, also, have been placed some plants immediately connected with the habitation of man, such as *Racodium cellare,* a fungus found on wine casks, *Conferva fenestralis,* an alga produced on window panes, and *Conferva dendrita,* one developed on paper. Some plants, as *Sempervivum tectorum,* select the roofs of houses.

11. Plants growing in vegetable mould; such as bog-plants, or those growing on wet soil, so soft that it yields to the foot but rises again, and marsh plants growing in wet soil, which sinks under the foot and does not rise. To the former class belong such plants as *Pinguicula alpina,* and *Primula farinosa;* to the latter, such as *Menyanthes, Comarum, Bidens cernua.*

12. Forest plants, including trees which live in society, as the Oak, the Beech, Firs, &c., and the plants which grow under their shelter, as the greater part of the European Orchises, some species of *Carex* and *Orobanche.* Some plants especially grow in pine and fir-woods, as *Linnæa borealis,* and some Pyrolas.

13. Plants of sterile places, found in barren tracts by road sides. This is a heterogeneous class, and contains many plants of uncertain characters. Under it are included the plants of uncultivated grounds, as those found on moors, where *Calluna vulgaris,* common heather, and various Heaths, Juniper, *Andromeda,* and some species of Polytrichum occur.

14. Plants of the thickets or hedges, comprehending the small shrubs which constitute the hedge or thicket, as the Hawthorn and Sweet-briar; and the herbaceous plants which grow at the foot of these shrubs, as *Adoxa,* Wood sorrel, Violets; and those which climb among their numerous branches, as Bryony, Black Bryony, Honeysuckle, Travellers' joy, and some species of *Lathyrus.*

15. Plants of the mountains, which De Candolle proposes to divide into two sections:—1. Those which grow on alpine mountains, the summits of which are covered with perpetual snow, and where, during the heat of summer, there is a continued and abundant flow of moisture, as numerous Saxifrages, Gentians, Primroses, and Rhododendrons. 2. Those inhabiting mountains, on which the snow disappears during summer, as several species of snap-dragon, among others the Alpine snapdragon, Umbelliferous plants, chiefly belonging to the genus *Seseli,* meadow Saxifrage, Labiate plants, &c.

C. *Plants growing in Special Localities.*

16. Parasitic plants, which derive their nourishment from other vegetables, and which consequently may be found in all the preceding situations, as the Mistletoe, species of *Orobanche, Cuscuta,* (Dodder,) *Loranthus, Rafflesia,* and numerous fungi.

17. Pseudo-parasitic plants or Epiphytes, which live upon dead vegetables, as Lichens, Mosses, &c., or upon the bark of living vegetables, but do not derive much nourishment from them; as *Epidendrum, Aerides,* and other Orchids, as well as *Tillandsia, Bromelia, Pothos,* and other air plants.

18. Subterranean plants, or those which live under ground, or in mines and caves, almost entirely excluded from the light; as *Byssus,* Truffles, and some other cryptogamic plants.

19. Plants which vegetate in hot springs, the temperature of which ranges from 80° to 150° of Fahrenheit's thermometer, as *Vitex agnus-castus,* and several cryptogamous plants, as *Ulva thermalis,* the hot-spring laver.

20. Plants which are developed in artificial infusions, or liquors, as various kinds of *Mucor,* causing mouldiness.

21. Plants growing on living animals; as species of *Sphæria* and *Sarcinula* and various other Fungi and Algæ.

22. Plants growing on certain kinds of decaying animal matter, such as species of *Onygena,* found on the hoofs of horses, feathers of birds, &c., some species of Fungi, which grow only on the dung of animals, and certain species of *Splachnum.*

Of these groups of plants a large number were recognised by De Candolle, the others being added by Bory St. Vincent. We next give the more generally recognised and more geographical divisions of Schouw, which are based on various observations made in many parts of the world, and agree with the conclusions arrived at by Humboldt and others, who have carefully studied this important department of Physical Geography:—

PLANTS GROUPED IN GEOGRAPHICAL REGIONS.

I. *The region of Saxifrages and Mosses, or the Alpine Arctic Flora.*—This region is characterised by the abundance of mosses and lichens, the presence of the saxifrages, gentians, the chickweed-tribe, sedges and willows; the total absence of tropical families; a notable decrease of the forms peculiar to the temperate zone; by forests of firs and birches, and an absence of other forest trees; the small number of annual plants, and the prevalence of perennial species; and finally a greater liveliness in their simple colours. This region is divided into two provinces. 1. The province of the *Carices*, or the Arctic Flora, which comprehends all the countries within the polar circle, with some parts of America, Kamtschatka, New Britain, Canada, Labrador, Greenland, and the mountains of Scotland and Scandinavia. 2. The province of primroses and rampions, or the Alpine Flora of the South of Europe, which embraces the flora of the Pyrenees, Switzerland, the Tyrol, Savoy, &c., the mountains of Greece, the Apennines, and probably the mountains of Spain.

II. *The region of the Umbelliferous and Cruciferous Plants*, (to which the hemlock, parsley, wallflower, cresses, &c., belong.)—These tribes are here in much greater number than in any other region; roses, crowfoots, mushrooms, amentaceous and coniferous plants are also very numerous; the abundance of *Carices* and the fall of the leaves of almost all the trees during winter form also the chief features of this division. It may be separated into two distinct provinces. 1. The province of the Cichoraceæ (including the sow-thistle, dandelion, lettuce, &c.), which embraces all the north of Europe, not comprehended in the preceding region—namely, Britain, the north of France, the Netherlands, Germany, Denmark, Poland, Hungary, and the greater part of European Russia. 1. The province of the *Astragali* and *Cynarocephalæ* (to which the milkvetch, burdock, thistle, &c., belong), which includes a part of Asiatic Russia and the countries about Mount Caucasus. The cultivated plants include those most useful and important in the temperate zones.

III. *The region of the Labiatæ and Caryophyllæ*, (to which the pink, catchfly, sandworts, &c., belong), or the Mediterranean Flora.—It is distinguished by the abundance of the plants belonging to these two orders. Some tropical families are also met with, such as palms, laurels, arums, plants yielding balsam and turpentine, grasses belonging to the genus *Panicum*, or millet, and the true *Cryperaceæ*, or sedges. The forests are composed chiefly of the amentaceous and coniferous tribes, as birches, oaks, &c., the copses of *Ericaceæ*, or heath tribe, and *Terebinthaceæ*, as the mastich, &c. We meet here with a great number of evergreen trees. Vegetation never ceases entirely, but verdant meadows are more rare. Schouw divides this region into five provinces. 1. The province of the cistuses, including Spain and Portugal. 2. The province of the sage and scabious, the south of France, Italy and Sicily. 3. The province of the shrubby *Labiatæ*, the Levant, Greece, Asia Minor, and the southern part of the Caucasian countries. 4. The Atlantic province, the north of Africa, of which he does not yet know any distinctive character. 5. The province of the houseleeks, the Canary Isles, and probably also the Azores, Madeira, and the north-west coast of Africa. Many houseleeks and some spurges with naked and spring stems particularly characterise this province.

IV. *The region of the Rhamni and Caprifoliaceæ*, (to which the buckthorn and honeysuckle belong,) or the Japanese region.—This region is as yet too little known to enable us to determine accurately its characteristic features. It embraces the eastern temperate part of the old continent, namely, Japan, the north of China, and Chinese Tartary. Its vegetation appears to occupy a middle place between that of Europe and that of North America, approaching more to the tropical than to the European.

V. *The region of Asters and Solidagos*, (Michaelmas daisies and golden-rods.)—This is marked by the great number of species belonging to these two genera, by the great variety of oaks and firs, the small number of *cruciferous* and *umbelliferous* plants, the total absence of the heath, and the presence of more numerous species of whortleberry than are to be met with in Europe. It comprehends the whole of the eastern part of North America, with the exception of what belongs to the first region. It has been divided into two provinces. 1. That of the south, which embraces the Floridas, Alabama, Mississippi, Louisiania, Georgia, and the Carolinas. 2. That of the north, which includes the other states of North America, such as Virginia, Pennsylvania, New York, &c.

VI. *The region of Magnolias*, comprising the most southern parts of North America. —The tropical forms which show themselves more frequently than on a similar parallel of the old continent, are the chief feature in the vegetation.

VII. *The region of Cactuses, Peppers, and Melastomas.*—These families are here predominant, both as regards the number of the species and of the individual plants. It is divided into three provinces. 1. The province of the ferns and orchises, comprehending the West Indian Islands. 2 The province of the palms, the lower parts of Mexico, New Granada, Guiana, and Peru. 3. Brazil also seems to form a province, and may perhaps constitute a region of itself.

VIII. *The region of Cinchonæ,* or Medicinal Barks, which comprises a part of the elevated regions of South America included in the torrid zone. The *Cinchonæ* belongs exclusively to this region and forms its principal feature.

IX. *The region of Escallonias, Whortleberries, and Winter's Barks.* — It embraces the highest parts of South America. We also meet with Alpine plants, as saxifrages, whitlow-grass, sandworts, sedges, and gentians. Perhaps also the mountains of Mexico belong to this region, although they may form a separate province, that of the oaks and firs.

X. *The Chilian region.*—The Flora of Chili differs essentially from those of New Holland, the Cape of Good Hope, and New Zealand, although an approach to them is observable in the genera *Goodenia, Araucaria,* (Chilian pine,) *Protea, Gunnera,* and *Ancistrum.*

XI. *The region of Arborescent Compositæ,* (or arborescent plants, with flowers like the dandelion, daisy, &c.)—The great number of syngenesious plants, more particularly of the family of Boopideæ, forms the chief feature of this flora, which approaches in a remarkable manner to that of Europe, whilst it differs entirely from those of Chili, the Cape, and New Holland. This region comprehends the lower part of the basin of La Plata, and the plains which extend to the west of Buenos Ayres.

XII. *The Antarctic region,* formed by the countries near the Straits of Magellan.—There is a considerable affinity between the vegetation here and what is seen in the north temperate zone. Polar forms, however, display themselves in the species of saxifrage, gentian, arbutus, and primrose. There is also a resemblance between the flora of this region and those of the mountains of South America, of Chili, the Cape, and New Holland.

XIII. *The region of New Zealand.*—This flora, besides the plants peculiar to New Zealand, comprehends several others which belong to the extremities of America, Africa, and Australia, or New Holland.

XIV. *The region of Epacrides and Eucalypti.*—It comprehends the temperate parts of New Holland and Van Diemen's Land. Besides the two families whence it receives its name, it is characterised by the presence of a great number of *Proteaceæ,* myrtles, *Stylideæ, Restiaceæ, Diosmeæ, Acacias, &c.*

XV. *The region of Mesembryanthema, or Fig Marigolds and Stapelias.*—These two genera, as well as the heaths, are very abundant here. The latter is found in greater quantity here than anywhere else. The region embraces the southern extremity of Africa.

XVI. *The region of Western Africa.*—We are only acquainted with Guinea and Congo, the vegetation of which is a mixture of the Floras of Asia and America, though most resembling the former. This region is characterized by a considerable number of grasses and sedges, and the peculiar genus *Adansonia,* the baobab, (the largest known tree in the world.)

XVII. *The region of Eastern Africa.*—In regard to the eastern coast of Africa, our knowledge is very imperfect. The region is chiefly distinguished by the genera *Danais, Ambora, Dombeya,* and *Senacia.*

XVIII. *The region of the Scitamineæ* (of the turmeric, cardamom, Indian shot, &c.), or the Indian Flora. The *Scitamineæ* here are much more numerous than in America, as well as the *leguminosæ,* such as pease, broom, &c., *cucurbitaceæ* or the cucumber tribe, and *tiliaceæ,* or the lime-tree tribe, although in a less degree. In consequence of the imperfect state of the science, we cannot subdivide this region into provinces. It comprehends India, east and west of the Ganges, the islands of Madagascar, Bourbon, and Mauritius, those between India and New Holland, and perhaps the tropical part of this last continent.

XIX. *The mountains of India* ought to form one or two regions, the vegetation of which differs from that of the plains. These countries, perhaps, constitute one region with the whole of central Asia.

XX. *The Floras of Cochin China, Tonquin, and the north of China,* notwithstanding their resemblance to that of India, present a sufficient number of peculiar indigenous plants to constitute a distinct region.

XXI. *The Flora of Arabia and Persia,* differing from that of India and the Mediterranean, forms a particular botanical region, characterised by the numerous species of *cassia* and *mimosa*, (to which senna, the sensitive plant, &c., belong,) which are found in it. It appears probable that Nubia and a part of central Asia belong to it. Abyssinia, the elevated parts of which possess such a different climate, may perhaps form one of the great subdivisions, or even a totally distinct region.

XXII. *The Islands of the South Sea* which lie within the tropics form undoubtedly a separate region, though with but a slender degree of peculiarity. Among 214 genera, 173 are found in India, and most of the remainder are in common with America. The bread-fruit tree is among the characteristics of these islands, although it is not confined to this region.

Marine plants are also confined to particular regions, from causes analogous to those which limit or favour the extension of terrestrial plants. Thus, the Northern Ocean from the pole to the fortieth degree, the Sea of the Antilles, the eastern coasts of South America, those of New Holland, the Indian Archipelago, the Mediterranean, the Red Sea, &c., present so many large marine regions, each of which possesses a peculiar marine vegetation and often characteristic plants.

133 *Distribution of Plants in Vertical Space.*—Just as the mean annual temperature of any part of the Earth is found to diminish as we advance from the equator towards the poles, although greatly modified in different districts from local circumstances, so does it decrease regularly and rapidly as we ascend from the plains into the higher regions of the atmosphere, so that starting from the burning heat of central America, at or near the sea level, we pass quickly through all changes of temperature, till in a few hours' travelling we reach the icy region where perpetual snow and ice prevent all vegetation. The most striking exemplification of the mere change of temperature is recognised in rising rapidly in a balloon; but when one ascends a high mountain, a similar but more gradual decrease of temperature is observed to correspond with striking differences in the vegetation. At the foot of the mountain the plants of the plain appear; these gradually vanish as we continue to mount—trees are found up to a certain height, but no further—then bushes prevail; after which, towards the extreme elevations, the bushes give place first to herbs, and at length to only a few lichens.

The traveller who has visited the countries to the north will, when ascending high mountains in southern latitudes, very soon enter regions amongst whose vegetation he will recognise northern plants. At the limit of permanent snow on these mountains he will miss but a few forms of the plants of the arctic zone, and even will find identical species which do not once appear in the plains in the whole space between the arctic regions and the summit of those mountains.

There is therefore a certain parallelism between the distribution of vegetation from the level of the sea to the limits of perpetual snow, and that from the equator to the poles, although the gradual change is far more rapid in the former than in the latter case. This parallelism also exactly agrees with that which we find between the gradual decrease of heat from the equator to the poles, and that from the plain to the limit of perpetual snow.

In ascending from the level of the ocean in the temperate and frigid zones, we find as we rise upon the slopes of the mountains that plants decrease both in the size of the individuals and also in their numerical development, while in the tropics the mass of vegetation is more limited in the plains than in the lower mountain regions. This is also the case with the greater variety of species which in common with these decrease in an upward direction, and the remark is applicable especially to the temperate zones, since in the cold zones the plants of higher regions cannot differ much from those of the plains, because the snow limits have but little absolute elevation. The distance of the limits of trees and shrubs from the snow line is also greater in the torrid than in the temperate and frigid zones.

In central and southern Europe the following difference is observed between the flora of the plains and that of mountains of 4000 feet elevation. The proportion of monocotyledons to dicotyledons, which in the plains is as one to four, decreases with the elevation (but only on dry mountain slopes), till at the height of 8526 feet it is as one to seven, and in particular creases even as one to nine. Moist mountain slopes, on the contrary, favour the growth of monocotyledons, as here the proportion becomes one to three.

The tropical families which have representatives in the plains disappear altogether in the mountain flora, and this is also the case with those families which have their maximum number of species in the torrid zone. Examples of the first are found in the palms, and of the second in the laurels. Other families which have their maximum in the torrid and diminish in the temperate zone, exhibit this decrease still more on the slopes of mountains, as exemplified in the *Leguminosæ* and *Euphorbiaceæ.*

Among the families which have their maximum in the temperate zone, there are many that undergo but little change with increased elevation, as the well known families *Compositæ, Cruciferæ, Umbelliferæ, Rosaceæ,* and others; while some families decrease both towards the poles and the snow line in vertical space (e.g. *Liliaceæ, Labiatæ, &c.*); and others, again, appear as subordinate groups, which have their maximum in the higher regions.

In some cases the proportion becomes greater with increased elevation, as seen especially with the saxifrages, mosses, and lichens.

In the European Alps the *Compositæ,* from the number of species, are the prevailing family; after these follow, in nearly equal number, the *Cyperaceæ, Alsineæ, Gramineæ, Cruciferæ, Leguminosæ, Rosaceæ, Saxifrageæ,* and *Umbelliferæ;* but the mass of vegetation is formed by the Catkin-bearing plants (*Amentaceæ*), the grasses, and the genus *Rhododendron.* As characteristic marks of the Alpine flora may be noticed, first, that the number of annuals is very small; second, that the flowers are of great size in proportion to the whole plant; and third, that the colour of the flowers, and indeed of the entire plants, is brighter and purer than in the plains.

Alpine plants afford more nourishment to cattle than those grown on plains, and plants with thorns or very hairy plants are seldom found in the Alpine regions.

On ascending a mountain in the torrid zone, as in the Cordillera of the Andes, the tropical families disappear altogether at the height of about 7000 feet, or at least become represented by single species; the number of species gradually decreasing, and those of families which attain their maximum in temperate zones replacing them and increasing with the height. Thus of 327 genera, to which the plants on the declivity of the Andes at a height of 7800 feet and upwards belong, as many as 180, or more than one-half, are common to the temperate zone.

As, therefore, the physiognomy of the vegetable kingdom is characterised by certain plants in the different latitudinal zones from the equator to the poles, so is it also in the vertical direction in the mountain regions which correspond with the zones; and proceeding from the vegetation of the equatorial zone, we follow the series of vegetable regions in ascending lines one after the other, and may compare them with the different zones as follows:—

1. Region of palms and bananas	Equatorial zone.
2. Tree ferns and figs	Tropical zone.
3. Myrtles and laurels	Sub-tropical zone.
4. Evergreen trees	Warm temperate zone.
5. European trees	Cold temperate zone.
6. Pines	Sub-arctic zone.
7. Rhododendrons	Arctic zone.
8. Alpine plants	Polar zone.

This table shows that each of the zones of higher latitudes possesses a region less than that which precedes it, but it must also be understood that many modifications occur in nature in particular localities. Thus the limit of trees in the equatorial zone, in the Andes of Quito, is marked by an *Escallonia* (not a Conifer), while in the temperate zone, in the Himalayans, the oak is the last tree at 11,500 feet above the sea on the south side, and the birch the last on the north side at 14,000 feet. Similar exceptions occur with regard to the limit of shrubs.*

134 *Range of Cultivated Plants.*—Several natural families and many genera and species of plants bear so directly on the habits and even existence of man in the country where they abound, that the subject of cultivated plants becomes of great interest in a treatise on Physical Geography. The plants of this kind resolve themselves into about five groups, which we will now consider separately. They are (1) the cereals, (2) the tuberous roots, (3) the trees bearing food, (4) the plants used in the preparation of luxuries, and (5) the plants used in the manufacture of various articles of clothing.

The CEREALS include a number of cultivated grasses bearing grain, of which wheat, barley, rye, oats, rice, maize, millet, buckwheat, &c., are in various countries the chief food of man. Of these the first four are generally used in Europe, rice in Asia, maize in America, and millet in Africa.

The culture of *Wheat* is carried on in every quarter of the globe, from latitude 60° to 64° in Europe to the torrid zone, and even at the equator at an altitude of about 3000 feet. Its vertical limits in South America are between 3600 and 10,000 feet, the grain being extremely productive at moderate altitudes in hot countries.

In the middle of the temperate zone, as in France, its cultivation is not successful above 5400 feet. The productiveness in cold countries with indifferent cultivation is not more than five or six fold; but in Hungary, Croatia, and Sclavonia, it is from eight to ten fold; in La Plata twelve fold; in the north of Mexico seventeen fold, and in the equatorial parts of the same country twenty-four, and even in favourable seasons thirty-five fold. As instances of extraordinary productiveness, Humboldt mentions an instance in Mexico of wheat plants sending up forty, sixty, and even seventy stalks, the ears of which were almost equally well filled, and contained from 100 to 120 grains each.

The other grains of Europe, barley, rye, and oats, are only cultivated as bread corns in the northern and colder countries. In Scandinavia, barley extends to 70° north, rye to 67°, oats to 65°, wheat not being cultivated with profit above 62°. So also these other cereals are grown at higher elevations than wheat, barley being cultivated in Peru for fodder, at the very extreme elevation of 13,800 feet above the sea.

There is much doubt as to the native country of the cereals. It has been supposed that wheat grows wild in Asia Minor and Persia, and barley in the north of Africa—perhaps Egypt. Oats do not appear to have been used by the ancients, but though they have been recently introduced as cultivated grain, their native habitat is extremely doubtful.

Rice probably supports a larger number of persons on the Earth than any other single article of human food, as its use is universal in eastern and southern Asia, and it is common in the north of Africa and the south of Europe, besides being now extensively cultivated in North America. There are two varieties of this vegetable, one growing on mountain slopes, and the other in swamps; and of these, the latter, the most common, and also the most productive, yielding one hundred or one hundred and twenty fold, and in some places even four hundred fold; while the mountain rice does not produce more than forty fold when grown continually on the same ground, or eighty fold on newly prepared spots. This kind, however, though less rapidly increased, is more esteemed and more valuable, inasmuch as it may be kept longer without spoiling.

Maize is indigenous only in America, and thrives best in the hottest and dampest tropical climates, yielding in some cases as much as eight hundred fold, and in less fertile lands three hundred or four hundred fold; while one hundred fold is regarded as a poor crop in tropical countries,

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* Johnston's *Physical Atlas*, 'The Geographical Distribution of Plants.'

though in the temperate zone, as in California, it does not produce more than seventy fold, and in still colder countries the yield is still smaller.

Maize has been introduced into Asia, and its growth had spread over India, China, and Japan very many centuries ago. It is not, however, so favourite a food as rice. In America, the vertical limits of its growth are very high, as it has been actually cultivated artificially at an elevation of 12,800 feet, and Humboldt describes vast maize fields on the plateau of Mexico 8680 feet above the sea.

Turkey millet or *Negro-corn* is also a grain of hot countries, much grown in the East Indies, and ranging to very considerable heights. Its limits in other respects are not accurately determined.

THE TUBEROUS ROOTS.—Of these, the *potato* is beyond doubt the best known, and most widely spread in temperate climates. It was introduced about 260 years ago from America, (where it appears to be indigenous in the cold regions, at considerable heights on the Andes,) and within a very short space of time its cultivation has extended over the whole of Europe, up to latitude seventy-one degrees north, and has reached the lower plains of India, China, and Japan, the South Sea Islands, Australia, and New Zealand. The true native country and natural limits of this useful food plant are not accurately known; but it is supposed *not* to be indigenous in North America, whence it was first brought to Europe. It is to this day chiefly and most carefully cultivated in South America.

The *Arum* or *Taro*, as it is called in the Sandwich Islands, is an extremely important tuberous root, cultivated with extraordinary care in the hottest part of the torrid zone, and ranging now in the East Indies and China, in the West Indies, in Africa, and at several points in the continent of America. The tube of this plant, which requires almost more than any other the intense heat of a vertical sun to ripen it properly, attains the size of a child's head, and is very delicate in flavour. It requires much moisture. and is limited in vertical distribution to about 1000 feet above the sea.

The *Manioc*, from which is made Cassava bread, is another important tropical food plant, cultivated in America, where it is probably indigenous, and also in Guinea. Tapioca is made from this plant.

The *Batata*, the *Yam*, and some other tuberous roots, are very extensively used for food in all parts of the torrid zone. Yams have been recorded to weigh as much as 474 pounds, being nine and a half feet in circumference, but the usual dimensions and weight are very much smaller.

THE FOOD-BEARING FRUIT TREES.—Of these, the *Bread-fruit* is one of the most important, but is confined to the torrid zone, and chiefly abounds in the islands of the Indian Archipelago and the South Sea. It has never been observed in the wild state.

It is the fruit of this tree that furnishes food, and the fruits are very abundant during eight or nine months of the year, the dried and prepared bread made from them lasting during the rest of the year. Each fruit is round, and often of considerable size; it is generally plucked when unripe, and is peeled, wrapped in leaves, and baked.

The *Plantain* or *Banana* yields another exceedingly common and most nutritious food to the inhabitants of tropical countries. Several species of the genus *Musa* produce, however, fruits that receive this name, and all of them are occasionally cultivated, the process of culture being exceedingly simple, and merely consisting of the removal of the old trunks after they have borne fruit.

The plantain ranges very wide, and it is doubtful whether its native country is in the Old or New World, or whether some species are not indigenous in both. In the plains it can be cultivated as far as thirty degrees, or even thirty-five degrees of latitude, and on the mountains some species reach nearly 3000 feet above the sea. According to Humboldt, the banana yields in a given extent of ground forty-four times as much nutritive matter as the potato, and 133 times as much as wheat.

The *Cocoa palm* is an inhabitant of the coast, and is incredibly abundant in the South Sea Islands, and those of the Indian Archipelago, nearly three millions of the nuts having been exported in one year from Ceylon alone, where, indeed, there is a forest of cocoa palms several leagues broad, stretching along the coast for twenty-six miles, and containing eleven millions of full-grown trees. Each tree will bear from 200 to 300 nuts in the year, and will live for nearly a century. The limits of growth of this palm are about twenty-eight degrees of latitude, and a height of about 2000 feet.

The *Date palm* is another tree belonging to the same family, and its fruit is also extensively used as food. It is indigenous in the north of Africa, in Asia Minor, and Arabia, and has been transported as far east as Batavia. It will grow in Italy, in latitude forty-four degrees, and in Sicily to the height of 1700 feet, but is not there fruitful. In Arabia and Egypt, it affords the chief food of the inhabitants.

The *Sago palms*, of which there are several, are confined to the Eastern Archipelago, and the palm which supplies the large quantity of palm oil used in commerce to the coast of Guinea. Other palms are useful for various purposes of luxury, but not as principal articles of food.

The *Olive* is a most valuable plant, growing in South Europe, between the limits of forty-four and a half degrees, and thirty-six degrees north latitude; but it cannot endure severe winters, and thus cannot be generally grown at considerable elevations. In warmer climates than those of Europe, it appears to grow more luxuriantly, and has been introduced with success into America. It is also grown in many parts of Mexico.

The *Chestnut* spreads over the whole south of Europe, but finds its true home in the warmer part of the temperate zone. It reaches eastwards to China, and thus crosses the Old World from Spain to the Pacific. By art the chestnut has been induced also to grow north of the Alps, and is now found in northern Germany and England. Many other trees supply fruits occasionally used as the food of man, but they do not form a supply on which he can safely and constantly depend.

FOOD-PLANTS USED AS LUXURIES.—Of these the *Sugar cane* is, perhaps, the most important. Indigenous in the Old World and cultivated in China and the eastern islands before the historical era, this valuable plant was introduced into America by the Spaniards about the year 1520, and since then has been greatly cultivated in the tropical islands of the West Indies, and also on the mainland.

The tract within which it can be cultivated stretches far beyond the tropics, reaching even to the latitude of South Europe, and in Mexico and Columbia it may be grown at the height of 6000 feet on the warm mountain slopes. It is understood to succeed best with a mean temperature of 76° or 77°, but will grow with advantage when the temperature is not below 67° or 68°. The total amount of sugar produced was calculated in 1833 to exceed 600,000 tons. There are several varieties of the sugar-cane, and the raw cane when ripe is much used as food.

The *Tea plant* is another of those shrubs which have become highly important, but this is owing to the presence of a stimulant rather than any nutritive quality. China is the native country of this plant, and it there extends as far north as 40°, growing also in the mountain districts to the south, particularly on those mountains which separate China from the Birman empire. The British territory in North India, especially Assam, has also been found favourable to the growth of tea, and indeed it seems to flourish throughout the sub-tropical zone in the eastern part of the Old World. *Coffee*, a very important substitute for tea in various countries, is more tropical in its habits than tea, but admits of great range artificially, while *mate*, or Paraguay tea, serves as the substitute in Brazil and many parts of South America.

The *Vine* is a plant which has been employed by man in the manufacture of a spirituous liquor from the very earliest period, and has been so long cultivated and so widely transported artificially, that its native station is not certainly known, nor can it be distinctly made out, whether all the varieties now used (as many as 200 might be enumerated) have been derived originally from one or several distinct species.

We have already had occasion to speak of the limits of culture of the vine, which is regulated much less by mean temperature than by summer heat, but it is chiefly the duration of the summer that influences the ripening of the fruit. Excellent wine is made with a mean temperature 60° Fah. and it is probable, that if damp and too much moisture are avoided, every greater heat will also succeed. Although the Old World is the natural habitat of this plant, it has been introduced into America, and flourishes on both sides of that Continent, and in both the northern and southern hemisphere, wherever the limits of temperature and dryness are obtained. Its polar limits may be considered to be between 49° and 55° in the northern, and about 40° in the southern hemisphere.

Tobacco, the *Betel nut*, and *Opium* are all very important and very widely spread vegetable productions, used in various parts of the world for their stimulating and soothing properties. The former seems to have been known in China long before its introduction into Europe from America, and several species are determined ranging even as far as 55° N. lat. and grown very extensively in various parts of central Europe, while a large quantity is also cultivated in New Zealand. The largest quantity and best kinds of this plant are grown in hot countries, especially in the tropical parts of America and the West Indian Islands. The *betel nut*, obtained from the Areca palm, and used with what is called the betel pepper, is employed in the same manner on the shores of eastern Asia, and in the various islands of the Indian Archipelago. *Opium*, again, is very largely used for similar purposes by the Turks, Malays, and Chinese. Some idea may be formed of the extent to which it is grown, from the fact that in fourteen years, from 1818 to 1831, above fourteen millions of pounds weight were conveyed into China through Canton alone, besides an enormous quantity consumed by the Malays, the inhabitants of Cochin China and Siam, as well as India and Persia.

PLANTS USED IN CLOTHING.—Besides the food plants there are others also greatly modified by civilization, and conveyed by man to distant parts of the Earth, but only because from them he is enabled to derive a portion of the clothing which he requires to shelter him from cold, and enable him to withstand the rigours of winter in most parts of the Earth. The *Cotton plant* and *Hemp* are the plants most important in this respect—the former, however, being the most widely spread, and perhaps the most useful, is that which deserves chief attention. Not only is the cotton plant cultivated in the tropical parts of every land of the Old and New World, but it extends far beyond the tropics even to countries whose mean temperature is not more than 62°, reaching thus the most southerly parts of Europe. The number of species of the tree is, however, large, and no doubt various species are indigenous in different localities. As to the quantity supplied, some idea may be formed from the statement that England is estimated to consume annually three hundred millions of pounds.

The *hemp* is also a plant of vast importance, and although its growth is greatly extended by culture, there can be little doubt that it is capable of much farther increase, if it were not that other plants in different countries supply the same material. Thus, in New Zealand a large and handsome reed (*Phormium tenax*) yields fibres capable of being spun into fine thread, and also made into the stoutest cables.

135 *General Considerations of the Representation of Plants in distant Botanical Centres.*—The general laws of nature as derived from the observation of a vast multitude of facts connected with the distribution of vegetables seem to be—*first*, that certain districts originate distinct groups of plants which are capable of a wide range, although the actual extent of the range, both in space and time, is dependent on various external circumstances.

Such places are technically called 'specific centres.' *Secondly*, that in similar climates, whether in the same hemisphere at the same level or otherwise, there are either individuals of the same species, if circumstances have been favourable for their transport, or else that the species resemble each other so manifestly, as to be in a proper and simple sense 'representatives.' *Thirdly*, that in places not separated in latitude by any distinct natural barrier, such as a lofty mountain chain or a broad tract of sea, and situated in very different climates, and in different latitudes, there is a graduated transition from the flora of one district to that of another, generic forms lingering much longer than specific, and whole families being rarely obliterated till after a long series of changes. For places situated at very different levels the same observation is true, and the same law holds good, as is illustrated in the existence of palms and other tropical forms of vegetation far north and south of the tropics, on the one hand, and far above the ordinary limits we might have anticipated (judging only by temperature), on the other. *Fourthly*, that in spite of the usual absence of identical species in districts removed by a lofty chain of mountains, a broad tract of ocean, or a complete zone of temperature, there are some species which cannot at all be distinguished from each other in the floras of the arctic and antarctic zone—in those of New South Wales and north Europe, and in those of tropical Africa, Asia, and America. The rarity of such instances is not to be taken as any explanation or solution of the difficulty, for, if possible, it adds to it, nor has anything yet been suggested which really and importantly bears on the true question at issue. The cases of exception to the general rule also are of a nature which rather increase the puzzle, since in large intermediate areas certainly capable of supporting a particular kind of vegetation, the expected plants are not found, notwithstanding that at the two extremities some common species appear. It is perhaps only when we study carefully the distribution in time, that these apparent anomalies cease, and resolve themselves into the working out of one far more general and important law, according to which the succession of races as well as any single race is arranged, and the peopling of the world with an infinite but harmonious variety, which shall exhibit mutual relations throughout all time, is fully provided for.

We have chiefly directed attention in these observations to the physiognomy of plants, but the study of their statistics would lead to the same or nearly the same conclusion, though perhaps by a different path. In whatever way vegetation is considered, it is found to be distributed according to these or similar laws, and tending to bring out analogous results.*

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* Of somewhat more than 20,000 species of plants catalogued in De Candolle's *Prodromus*, it appears that 3210 are European; 5004, Asiatic; 3731, African; 2111, North American; 5742, South American; and 922, Australian. The island vegetation in each case is included in the list for the adjoining mainland.

CHAPTER XI.

THE DISTRIBUTION OF ANIMALS IN SPACE.

§ 136. Organization of animals. — 137. Classification of animals. — 138. Statistics of animals. — 139. Nature and degrees of resemblance amongst animals, and comparison of their structure. — 140. Natural grouping of animals in a FAUNA. — 141. Distribution of the Faunas. — 142. Arctic Fauna. — 143. Temperate Faunas. — 144. Tropical Faunas. — 145. Special distribution of *Quadrumana*. — 146. Distribution of *Carnivora*. — 147. Distribution of *Rodentia*. — 148. Distribution of *Ruminantia*. — 149. Distribution of *Pachydermata*. — 150. Distribution of the *Edentata* and *Marsupialia*. — 151. Distribution of *Birds*. — 152. Distribution of *Reptiles*. — 153. Distribution of the *Marine Vertebrata*. —154. Distribution of the *Articulata*. — 155. Distribution of the *Mollusca* and *Radiata*.

ORGANIZATION of Animals.—Animal life presents many points altogether peculiar, and exhibits forms of organization not less different from those afforded by plants than are seen in the latter when they are compared with inorganic substances. It will, therefore, be advisable briefly to consider the more essential of these before proceeding to the subject of the distribution of animals in space, and it is desirable to determine, as far as possible, the simplest forms of animal life, and their relations with organic matter of greater complexity, and with inorganic bodies.

The greater part of the structure of animals consists of tissues, of which fibre is the elementary form. There are two kinds of fibre, muscular and nervous, the one forming the flesh, and the other the brain, the spinal chord, and the nerves; and in the more highly organized forms several others occur, serving for various important purposes. In animals of less complicated structure, as in some of those called 'polypi,' and in infusorial animalcules, there are, however, myriads of individuals made up of nothing but cells in contact with each other.

The structure of animals is, in all the higher groups, so manifestly different from that of vegetables, that it would seem superfluous to allude to the points of distinction. The old definition, that minerals increase only by mechanical additions, while vegetables live, and animals live and move, is not, indeed, sufficiently accurate, since plants are sometimes endowed with a kind of instinct, and an appearance at least of voluntary motion, and animals, on the contrary, are sometimes almost without either instinct or the power of moving at will. In proportion as we descend to the lower forms of each, and compare them together, we find the differences less marked, so that it becomes at length difficult to pronounce whether an object before us is animal or plant. Thus, the sponges have so great a resemblance to some of the polypi, that they have generally been classed with animals.

Animals and plants differ in the relative predominance of the elements, oxygen, carbon, hydrogen, and nitrogen, of which they are composed. In vegetables hardly a trace of nitrogen is found, except in seeds and some special products, but it enters largely into the composition of animal tissues.

Another peculiarity of animals is the presence of limited cavities for the reception of certain important organs, such as the skull and chest in higher animals, and the abdomen in almost all. The possession of a digestive cavity involves marked differences between the two grand divisions of organic nature, for in plants the fluids absorbed by the roots are conveyed to the whole plant, by means of the trunk and branches, before they can reach the leaves, where they are to undergo a process analogous to digestion; while, on the contrary, the food of all animals passes at once into the digestive cavity, and is there elaborated into fluids, which being afterwards circulated through the body, are in a condition to be at once separated by the proper organs, and applied to the required purposes of renovation or increase.

Plants commence their existence usually from a seed, but admit also of increase by various means of mechanical division, having reference in all cases to the original nature of leaves as individuals of compound bodies.

Animals are developed from an egg, the animal germ being the result of successive transformations of the yolk, while nothing similar takes place in plants. The subsequent development of individuals is also different in the two kingdoms, as to method, form, and dimensions; the two latter varying during the whole life of the plant, but attaining a limit in the case of each species of animal, especially in those of complicated organization.

In the effects they produce on the air there is also an important difference, since animals consume oxygen and give off carbonic acid gas, while plants reverse the process, absorbing carbonic acid gas and giving off oxygen. If an animal, therefore, be confined in a small portion of air, or if of aquatic habits, in water containing air, this soon becomes so vitiated by respiration as to be unfit to sustain life; but if living plants are confined with the animal at the same time, the air is kept pure, and no difficulty is experienced. This, at least, is the case by day, and the practical effect of the compensation is very important, vegetation restoring to the atmosphere what is consumed by animal respiration.

Lastly, all animals have, more or less distinctly, voluntary motion and sensation, while plants, although endowed with a certain sensibility, appear to have neither true sensation nor actual volition. Life in animals is manifested by two functions instead of only one, as in vegetables, and the organs of animal life which involve the possession of a certain amount of intelligence, relation, and selection, which enable us to approach at will our fellow-creatures, to perceive their existence and act accordingly, are quite distinct from those which merely affect the functions of vegetable life, such as nutrition and reproduction.

To understand the development of animals and the facts of chief importance in their structure and mutual relations, we must consider a little their different organs and functions, and as the possession of a nervous system is at once the characteristic of all animals, and the function which, when present in its highest form, is the main cause of the vast difference of intellectual and reasoning power traceable between species and families, this must first be discussed.

There appear to be in nature four principal types within which may be included all the varieties presented of this most important and essential characteristic of animal organization. These are—*first*, that in which the nervous system is grouped into two principal masses, the brain and the spinal marrow; *secondly*, where it is collected into a series of small ganglia, knots, or small brains of nervous matter, placed at intervals beneath the alimentary canal and connected by threads, and a somewhat larger ganglion placed above the œsophagus; *thirdly*, where the nervous matter is collected in a single ganglionic circle, the principal swellings of which are placed symmetrically above and below the œsophagus, and whence the filaments which supply the organs in different directions take their origin; and *fourthly*, where the nervous matter is distributed in a single ring encircling the mouth, disposed in a horizontal position and in a starlike form. The first type includes all animals called *vertebrated*, or having a back-bone; the second, the insects, crustaceans, and other animals, whose body is made up of rings or portions nearly detached; the third, all animals such as those inhabiting univalve and bivalve shells, (the mollusks, or soft animals, as they are called;) and the fourth, the star fishes and other radiated animals.

The nerves, thus important in communicating to the animal all impressions from without, are usually so arranged as to render particular organs acutely perceptive to what are called the senses, which are recognised as five in number, under the names, sight, hearing, smell, taste, and touch. The impressions communicated in this way produce voluntary or involuntary results, chiefly acting on the other functions of the body, of which the organs of locomotion, or prehension, and of mastication and digestion, are the most prominent.

Nutrition is a function absolutely essential to the continuance of life, and involves a continual interchange of substances between the animal body and the external world. 'In early life, during the period of growth, the amount of substances received is greater than that which is lost. At a later period, when the growth is completed, an equilibrium is established between the matters received and those rejected; while at a still later period, the equilibrium is again disturbed; more is rejected than retained; decrepitude begins, and at last the organism becomes exhausted, the functions cease, and death ensues.'*

The reproduction of animals is not less necessary for the continuance of the race than nutrition is for that of the individual. It is effected in plants, as we have seen, by the modifications of what appears to be part of a simple body, but is really an individual member of a highly complicated one. In animals it is almost universally accomplished by the association of individuals of two kinds, *males* and *females*, each characterised by peculiarities of structure and external appearance, and both necessary for the production and proper fertilization of the germ of the future individual.

All animals are produced from eggs, and when enveloped in this way are called *embryos*—the period passed in this condition being called the *embryonic period*. Eggs are usually oval or spherical in shape, and are contained in the body of the female in sacs called *ovaries*, being at that time of very minute size, and merely consisting of little cells containing what is called *yolk* or yolk-substance, with other similar cells, namely, the germinative vesicle and the germinating dot.

The number of eggs is large in proportion as the animal is of lower organization; thus the ovary of a herring contains more than 25,000 eggs, while that of birds does not contain more than one or two hundred, and the higher mammalia produce only one at a birth.

At a certain period the eggs leave the ovary, and being fertilized are either discharged by the animal (*laid*), or else remain within the body till the young is fully developed. Animals in which the former habit is usual are called *oviparous*, while those which produce living young are said to be *viviparous*, or in some cases *ovo-viviparous*.

The formation and development of the young animal within the egg is a most mysterious phenomenon, and the changes undergone differ materially in the various natural groups of animals. In some animals, there are intermediate conditions between the embryonic and perfect state, but generally, and indeed invariably in the more highly organized groups, the young as it emerges from the egg, or is born, possesses the external form and habits of the species. The metamorphoses in the exceptional cases are sometimes extremely curious, and their cause very difficult to comprehend.

137 *Classification of Animals.*—In considering the arrangements of the nervous system we have seen that four important distinctions can be drawn amongst animals, and these point to a natural division into four departments, which are generally called, respectively, I. VERTEBRATA; II. ARTICULATA; III. MOLLUSCA; IV. RADIATA.

Of these the vertebrata are conveniently grouped into four classes, which all have an internal skeleton with a back-bone for its axis. The classes are 1. *Mammals* (animals which suckle their young); 2. *Birds*; 3. *Reptiles*; and 4. *Fishes*. These divisions are all so well known and so natural that they

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* *Principles of Zoology*, by Agassiz and Gould, (Boston, 1848,) p. 72.

require no special description, but their subdivisions are also important. The most convenient arrangement is perhaps the following:—

CLASS MAMMALIA, (QUADRUPEDS AND BIPEDS.)

	Order.	Example.
I.	Bimana (*two-handed*)	Man.
II.	Quadrumana (*four-handed*)	Monkeys.
III.	Chiroptera (*finger-winged*)	Bats.
IV.	Insectivora (*insect-eating*)	Hedgehog.
V.	Plantigrade Carnivora	Bear, Badger.
VI.	Digitigrade Carnivora	Cat, Lion.
VII.	Amphibia (*aquatic mammals*)	Whale, Porpoise, Seal.
VIII.	Rodentia (*gnawing*)	Rat, Hare, Squirrel.
IX.	Ruminantia (*ruminating*)	Ox, Sheep, Deer.
X.	Pachydermata (*thick-skinned*)	Elephant, Rhinoceros, Pig, Horse.
XI.	Edentata (*toothless*)	Sloth, Ant-eater, Armadillo.
XII.	Marsupiata (*pouched*)	Opossum, Kangaroo.

CLASS AVES, (BIRDS.)

I.	Raptores (*birds of prey*)	Vultures, Hawks, Owls.
II.	Scansores (*climbers*)	Cuckoos, Woodpeckers, Goatsuckers.
III.	Oscines (*songsters*)	Sparrows, Linnets, Crows.
IV.	Gallinaceæ (*gallinaceous birds*)	Pheasants, Fowls, Pigeons.
V.	Grallatores (*waders*)	Herons, Bitterns, Plovers.
VI.	Natatores (*swimmers*)	Geese, Divers, Gulls.

CLASS REPTILIA, (REPTILES.)

I.	*Dinosauria*[*]	*Megalosaurus, Iguanodon.*
II.	*Enaliosauria*[*]	*Ichthyosaurus, Plesiosaurus.*
III.	Crocodilia	Crocodiles.
IV.	Lacertilia	Lizards.
V.	*Pterosauria*[*]	*Pterodactyl.*
VI.	Chelonia	Tortoises, Turtles.
VII.	Ophidia	Serpents.
VIII.	Batrachia	Frogs.

CLASS PISCES, (FISHES.)

I.	Ganoid (*scales splendent*)	Sturgeon.
II.	Placoid (*scales plated*)	Sharks and Rays.
III.	Ctenoid (*scales comb-shaped*)	Perch.
IV.	Cycloid (*scales circular*)	Cod, Herring.

The Articulata are divided conveniently into three classes—1. *Insects;* 2. *Crustaceans;* and 3. *Worms.* The Mollusca also into three—1. *Cephalopoda* (having locomotive and prehensile organs ranged round the mouth); 2. *Gasteropoda* (creeping on a flattened disc or foot); 3. *Acephala* (having no distinct head, and enclosed in a bivalve shell). The Radiata again are divided into three classes—1. *Echinoderms* (bearing spines on the external surface, like the sea-urchins); 2. *Acalephe* (jelly-fish, often stinging like nettles, as the medusæ); 3. *Polyps* (fixed like plants, and with a series of flexible arms round the mouth—often compound). The further subdivisions it is not necessary here to discuss.

The technical or natural history names of animals, as of plants, are composed of two terms, one generic, including a considerable variety of structure united by some marked and important characteristics, and the other specific or trivial, forming an adjective or qualifying addition to the generic designation. Several genera combined together (possessing some characters in common) are called a *family*—families are combined to form

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[*] Those orders and genera of which the names are printed in italics, are not now represented on the Earth by any existing species.

orders, and orders form *classes;* the various divisions corresponding to which names we have already enumerated in the preceding page.

Since the specific name is the ultimate point to which we arrive in classifying, it is important that every one should have a clear idea on this subject. A *Genus* is generally founded on some distinct peculiarities of anatomical structure; such as (in the case of a Vertebrate) the number, disposition, and proportions of the teeth, claws, fins, &c.; while a *Species* depends on characters which are sometimes external, sometimes apparently trivial, but which are always supposed to be sufficiently real to prevent accidental admixture of race. There is also recognised another and a lower distinction, that of *Variety*, which, unlike *Species*, includes apparent and possible mixtures of race. It has been usual to consider that nature has set a broad and marked barrier between species, not allowing of any infraction, but this appears to be in reality a somewhat arbitrary assumption, although there is no doubt that the production of varieties from what are generally regarded as distinct species is rarely effected, except under the influence of extraordinary external circumstances.*

The real difficulty in the case of animals, as in plants, arises from an occasional interference with what appears at first to be an universal law, that of the production of similar types in parts of the Earth widely removed, but of similar climate. We shall have occasion to revert to this part of the subject.

We quote the following from the introduction to a work already referred to (Agassiz and Gould's *Principles of Zoology*) as fitly concluding this section, by stating what is most required of the elements of Zoology for the purposes of Physical Geography:—

'For each of these groups, whether larger or smaller, we involuntarily picture in our minds an image made up of the traits which characterise the group. This ideal image is called a TYPE, a term which there is frequent occasion to employ in speaking of the Animal Kingdom. This image may correspond to some one member of the group, but it is rare that any one species embodies all our ideas of the class, family, or genus to which it belongs. Thus we have a general idea of a bird, but this idea does not correspond to any particular bird, or any particular character of a bird. It is not precisely an ostrich, an owl, a hen, or a sparrow; it is not because it has wings, or feathers, or two legs; or because it has the power of flight, or builds nests. Any or all these characters would not fully represent our idea of a bird, and yet every one has a distinct ideal notion of a bird, a fish, a quadruped, &c. It is common, however, to speak of the animal which embodies most fully the characters of a group as the type of that group. Thus we might, perhaps, regard an eagle as the type of a bird, the duck as the type of a swimming-bird, and the mallard as the type of a duck.'

138 *Statistics of Animals.*—It is not possible to appreciate the importance of the subject we are now considering, either with reference to the grand features of general Zoology, or the details concerning the distribution of animals, without some reference to actual statistics. It is not enough to regard nature generally with admiration, or even to study carefully some detached points—we must also become acquainted with the extent of material for observation and learn the true spirit that animates the whole. 'We must acquire a proper conception of the varied affinities which combine beings together, so as to make of them that vast picture in which each animal, each group, each class has its place, and from which nothing could be removed without destroying the proper meaning of the whole.'

It is only within a short time that Zoology has so far extended itself as to become fairly beyond the grasp of any single individual. A century ago, the number of known animals did not exceed 8000, and thus fewer species were known in the whole Animal Kingdom than are now contained in many private collections of certain families of insects merely.

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* This subject will be found considered in further detail in paragraph 166 in the chapter on Ethnology.

The number of vertebrate animals may now be estimated at 20,000. Of these there are about 1500 species of mammals pretty precisely known, and the number may probably extend to 2000.

There are about 4000 or 5000 species of birds well known, and the probable number is 6000.

The number of reptiles is about the same as that of mammals—namely, about 1500 described species, and 2000 in all.

The fishes are more numerous. The number in the museums of Europe are about 5000 to 6000 species, but the total number may extend to 10,000.

The invertebrata are much more numerous. Of Mollusca there are probably from 8000 to 10,000 species in collections. There are collections of marine shells, bivalve and univalve, which amount to 5000 or 6000, and collections of land and freshwater shells extending to 2000 species. The total number of mollusks may probably exceed 15,000 species.

Among the Articulata it is difficult to estimate the number of species. There are collections of coleopterous insects which number from 20,000 to 25,000 species, and it is quite probable that by uniting the principal collections 60,000 or 80,000 species might now be counted. For the whole department of Articulata, comprising the crustacea, cirrhipeda insects, red-blooded worms, intestinal worms, and infusoria, so far as they belong to the department, the number would already amount to 100,000, and may be safely estimated as reaching double that sum.

The Radiata, including the echini, starfishes, medusæ, and polyps, cannot be estimated at less than 10,000 species. We may thus present the following tabular view.

	Known.	Estimated.	Known number of species.	Estimated number of species.
Mammals	1,500 ...	2,000		
Birds	5,000 ...	6,000		
Reptiles	1,500 ...	2,000		
Fishes	6,000 ...	10,000		
Total Vertebrata			14,000	20,000
Mollusca			10,000	15,000
Articulata			100,000	200,000
Radiata			10,000	10,000
Grand total			134,000	250,000

This large number of species of animals must be still further increased, and perhaps even doubled, if we include also those no longer represented, but whose remains are preserved to us in the strata of the Earth's crust. These will, however, require separate consideration.

139 *Nature and Degrees of Resemblance amongst Animals, and Comparison of their Structure.*—There is no subject more important to the general student of natural history, and there is none which has more worthily occupied the attention of the best and most philosophic naturalists, than the true nature of those resemblances which are presented everywhere in nature, which evidently have important meaning, but which, when made use of, are so likely to lead their pursuer into error, that they are the very points on which the greatest and most mischievous mistakes have been made. We must endeavour here to make the reader acquainted with some of the simpler meanings of homology, analogy, and affinity, as they are required to be understood in considering the distribution of animals.

Analogy and homology are relations of simple resemblance in portions of the living framework without reference to identity of race, while affinity is a relation obtaining between the corresponding parts of animals of the same race—and thus, at the outset, there are important and real distinctions to be recognised. But there is more than this, and there are also important distinctions to be drawn between the former terms. An *analogue* has been defined to be 'a part or organ in one animal which has the same function, or does the same work as another part or organ in a different animal;' while a *homologue* is 'the same organ in different animals under every variety of form and function.' It will not be difficult to understand, from these definitions, something of the true meaning of the words on which so much stress has been laid, but a few examples will render their use still more clear.

In a very general way we may show this, by considering the nature of the wings by which various animals fly, the legs or arms which others use for walking and running, and the fins by means of which fishes swim—in a word, of the organs of locomotion. There is analogy between the wing of a butterfly and that of a bird, for both of them serve for flight, but they are not homologous, since a different organ is employed. On the other hand, the fore leg of a quadruped is homologous to the wing of a bird, but not strictly analogous, for the same organ is employed, but the same purpose is not attained. Thus, also, the fin of a porpoise is homologous to the fin of a fish, being at the same time analogous, since both are employed in swimming, and both are modifications of the same organ.

Affinities are different, and indicate closer relations. Thus, there is affinity between the leg and foot of a man and the paddle of a seal, for both are constructed on the same plan, and the affinity in this case is far more important than the analogy and homology that exist between seals and fishes, in their structure and habits. Affinities, rather than analogies and homologies, are therefore most useful in guiding us in the arrangement of animals.

Resemblances are traced not only in the parts of the individual or species, but in general external character, with regard to genera and larger groups. Usually we may consider, that in any natural arrangement, such as we have endeavoured to give, there will be resemblances of affinity between all species collected together in any group, whether large or small—that, in other words, all animals in the first place—all vertebrata in the next—all mammals in the third—all monkeys in the fourth—and all baboons in the fifth place, have different degrees of affinity, gradually becoming closer as the number of species included is smaller. On the other hand, there will be analogy between some vertebrata and some mollusca or articulata, between carnivorous quadrupeds and birds of prey, between different tribes of carnivora and so on; and thus each natural group of organic beings will present resemblances of different kinds, which must be estimated, each according to its true value, in any general view of the whole Animal Kingdom.

It is important also to remember, that investigations concerning the true nature and relations of animals should not be limited to the adult, but extend over the whole course of development. If this is not done, some peculiarities of structure which are predominant at one period of life, will be exaggerated in importance, and others neglected. Thus, the organs of respiration, which appear to be most essential characters for classification, if we regard only the full-grown animal, are found, on examining and comparing their various states in the same individual, to be quite subservient to the nervous system. The comparative study of development is also not less valuable, as a means of estimating the relative position of animals. Thus, the caterpillar, in becoming a butterfly, passes from a lower to a higher development, and therefore, those animals, such as worms, which resemble the caterpillar, must occupy a lower rank than those approaching the butterfly.

All animals undergo changes, or *metamorphoses*, during the earlier period of their existence, although in many cases, especially in those of highest grade, these take place before birth, and during the embryonic period. It is only by connecting the two kinds of transformation—namely, those that take place before and those after birth, that we are furnished with means of ascertaining the relative perfection of animals; so that, in fact, such transformations become a natural key to the gradation of types. No one can properly appreciate the structure of animals and the difference of races, or comprehend, even in a very inferior degree, the law that governs the placing of groups in certain districts, adapts them a certain climate and certain food, and enables them to resist certain changes, without knowing something of the nature of analogy and affinity, and the changes of structure that take place in the individual and the species, in passing through all the various forms of its existence, as an organized being.

140 *Natural Grouping of Animals in a* 'FAUNA.'—The collection of animals inhabiting any particular region, including all the species, both aquatic and terrestrial, is called its *Fauna,* just as the plants of a country combine to form its Flora. It is not necessary that every species should be peculiar, only there must be some special distribution of families, genera, and species, and a preponderance of certain types, sufficiently important and prominent to impress upon the group well-marked features. Thus, the fauna of New Holland is characterised by the existence there of tribes of quadrupeds of the *Marsupial* order, that of South America by *Edentata.* The polar bear and reindeer are characteristic of the arctic regions of the Earth, and certain peculiarities of structure in monkeys at once distinguish the faunas of Asia and America, in those parts where monkeys appear.

As animals feed either on other animals, or on vegetables, it is evident that, ultimately, the distribution of animals will depend on vegetable life. Thus, there arises a relation between the fauna of a locality, its climate, and its flora; but although this is certainly very important, it must not be forgotten that while plants chiefly inhabit land, animals range far more widely, and exist to such an extent in water, that it has been even said, that the ocean is the true home of the Animal Kingdom, and this is certainly the case in those extreme latitudes where vegetable life entirely ceases, and where the sea teems with animals of all classes and all dimensions. The chief influence of extreme cold seems to be to render more uniform the distribution of species, so that many of the large quadrupeds, for example, are common to Europe, Asia, and America, within certain high latitudes, while the faunas of tropical Asia are totally distinct from those either of tropical Africa, or tropical America. A wide tract of deep sea, and the existence of broad desert tracts, lofty mountains, and distinct zones of climate on land, limit Faunas very strikingly, as we find on comparing the productions of the Cape of Good Hope with those of Cape Horn, and this is even the case when latitude and climate are very nearly similar. The depths of the ocean are, indeed, quite as impassable for marine species as high mountains are for terrestrial animals, and it would be as difficult for a fish or a mollusk to cross from the coast of Europe to that of America, as it would be for a reindeer to pass from the arctic to the antarctic regions across the torrid zone. It is probable that the deepest parts of the ocean are absolutely untenanted, for there seem there no means of subsistence, and few animals are organized so as to resist the pressure of a column of water many thousand fathoms in height.

The animal inhabitants of the sea are, therefore, as strictly limited to districts as those of the land; and as by far the larger proportion depend on the adjacent shores more or less for their means of existence and their shelter from natural enemies, no doubt the limits of the marine are less easily defined than those of terrestrial Faunas, but still marked differences are discernible, while freshwater species vary, not only in different zones, but even in the rivers and lakes of the same district.

The range of species does not depend on powers of locomotion, but on the contrary, animals which move slowly and with difficulty, generally have a wide range, while those which are active are often very narrowly limited. Thus, the common oyster extends on the American coast from Cape Cod to the Carolinas, and is, as we know, also common over a long line of coast on this side of the Atlantic, so that its range is absolutely very great; and when compared to that of some fleet animal, as the moose, appears enormous. It is indeed possible that the very want of power to travel really contributes to the diffusion of this and some other species, since when once removed they cannot return, and their eggs being left to the mercy of marine currents, may be drifted very far, while fishes depositing their spawn in sheltered bays and inlets, are secured from wide dispersion.

The nature of their food has an important bearing upon the grouping of animals, and upon the extent of their distribution. Carnivorous animals are generally less confined in their range than herbivorous ones, because their food is almost everywhere to be found. The herbivora, on the other hand, are restricted to the more limited regions corresponding to the different zones of vegetation. The same remark may be made with respect to birds. Birds of prey, like the eagle and vulture, have a much wider range than the granivorous and gallinaceous birds. Still, notwithstanding the facilities they have for change of place, even the birds that wander widest recognise limits which they do not overpass. The condor of the Cordilleras does not descend into the temperate regions of the United States; and yet it is not that he fears the cold, since he is frequently known to ascend even above the highest summits of the Andes, and disappears from view where the cold is most intense. Nor can it be from lack of prey.

Finally, to obtain a true picture of the zoological distribution of animals, not the terrestrial types alone, but the marine species, must also be included. Notwithstanding the uniform nature of the watery element, the animals which dwell in it are not dispersed at random, and though the limits of the marine may be less easily defined than those of the terrestrial fauna, still marked differences of the animals in the great basins are not less observable. Properly to apprehend how marine animals may be distributed into local faunas, it must be remembered that their residence is not in the high sea, but along the coasts of continents and on soundings. It is on the banks of Newfoundland, and not in the deep sea, that the great cod fishery is carried on; and it is well known that when fishes migrate, they take care to run along the shores. The range of marine species being therefore confined to the vicinity of the shores, their distribution must be subjected to laws similar to those which regulate the terrestrial faunas. As to the fresh-water fishes, not only do the species vary in the different zones, but even the different rivers of the same region have species peculiar to them, and not found in neighbouring streams.

A very influential cause in the distribution of aquatic animals is the depth of the water. The mollusks, and even the fishes found near the surface between high and low water, differ, in general, from those living at the depth of twenty or thirty feet, and these again are found to be different from those which are met with at a greater depth. Their colouring in particular varies according to the quantity of light they receive, as has also been shown to be the case with the marine plants.

It is sometimes the case that one or more animals are found upon a certain chain of mountains and not elsewhere; as for instance, the mountain sheep upon the Rocky Mountains, or the chamois and the ibex upon the Alps. The same is also the case on some of the wide plains or prairies. This, however, does not entitle such regions to be considered as having an independent fauna, any more than a lake is to be regarded as having a peculiar fauna exclusive of the animals of the surrounding country, merely because some of the species found in the lake may not ascend the rivers emptying into it. It is only when the whole group of animals inhabiting a region has such peculiarities as to give it a distinct character, when contrasted with animals found in surrounding regions, that it is to be regarded as a separate fauna. Such, for example, is the fauna of the great steppe or plain of Gobi, in Asia, and such also that of the chain of the Rocky Mountains may prove to be when the animals inhabiting them are better known.

The migration of animals might at first seem to present a serious difficulty in determining the character or the limits of a fauna; but this difficulty ceases, if we regard the country of an animal to be the place where it makes its habitual abode. As to birds, which of all animals wander the farthest, it may be laid down as a rule that they belong to the zone in which they breed. Thus the gulls, many of the ducks, mergansers, and divers, belonging to the boreal regions, though they pass a portion of the year with us. On the other hand, the swallows and martins, and many of the gallinaceous birds, belong to the temperate faunas, notwithstanding that they migrate during winter to the confines of the torrid zone. This rule does not apply to the fishes who annually leave their proper home and migrate to a distant region, merely for the purpose of spawning. The salmon, for example, comes down from the north to spawn on the coasts of Maine and Nova Scotia.

Few of the mammals, and these mostly of the tribe of Rodents, make extensive migrations. Among the most remarkable of these are the Kamtschatka rats. In spring they direct their course westward in immense troops, and after a very long journey, return again in autumn to their quarters, when their approach is anxiously awaited by the hunters, on account of the fine furs to be obtained from the numerous carnivora which always follow in their train. The migrations of the lemmings are marked by the devastations they commit along their course, as they come down from the borders of the Frozen Ocean to the valleys of Lapland and Norway; but their migrations are not periodical.

141 *Distribution of the Faunas.*—We have stated that all the faunas of the globe may be divided into three departments, corresponding to as many great climatal divisions—namely, the glacial or arctic, the temperate, and the tropical faunas. These three divisions appertain to both hemispheres, as we recede from the equator towards the north or south poles. It will hereafter be shown that the tropical and temperate faunas may be again divided into several zoological provinces, depending on longitude or on the peculiar configuration of the continents.

No continent is better calculated to give a correct idea of distribution into faunas as determined by climate than the continent of America, extending as it does across both hemispheres, and embracing all latitudes, so that all climates are represented upon it.

Let a traveller embark at Iceland, which is situated on the borders of the polar circle, with a view to observe, in a zoological aspect, the principal points along the eastern shore of America. The result of his observation will be very much as follows. Along the coast of Greenland and Iceland, and also along Baffin's Bay, he will meet with an unvaried fauna composed of animals which are, for the most part, identical with those of the arctic shores of Europe. It will be nearly the same along the Labrador coast.

As he approaches Newfoundland, he will see the landscape, and with it the fauna, assuming a somewhat more varied aspect. To the wide and naked, or turfy plains of the boreal regions succeed forests in which he will find various animals which dwell only in forests. Here the temperate fauna commences; still the number of species is not yet very considerable; but as he advances southwards along the coasts of Nova Scotia and New England, he finds these species gradually increasing, while those of the cold regions diminish, and at length entirely disappear, some few accidental or periodical visitors excepted, who wander during winter as far south as the Carolinas.

But it is after having passed the boundaries of the United States, among the Antilles, and more especially on the southern continent along the shores of the Orinoco and the Amazon, that our traveller will be forcibly struck with the astonishing variety of the animals which people the forests, the prairies, the rivers and the sea shores, most of which he will also find to be different from those of the northern continent. By this extraordinary richness of new forms he will become sensible that he is now in the domain of the tropical fauna.

Let him still travel on beyond the equator towards the tropic of Capricorn, and he will again find the scene change as he enters the regions where the sun casts his rays more obliquely, and where the contrast of the seasons is more marked. The vegetation will be less luxuriant, the palms will have disappeared to make place for other trees, the animals will be less varied, and the whole picture will recal to him, in some measure, what he witnessed in the United States. He will again find himself in the temperate regions, and this he will trace on, till he arrives at the extremity of the continent, the fauna and the flora becoming more and more impoverished as he approaches Cape Horn.

Finally, we know that there is a continent around the South Pole. Although we have as yet but very imperfect notions respecting the animals of this inhospitable clime, still the few which have already been observed there, all present a close analogy to those of the arctic region. It is another glacial fauna—namely, the antarctic. Having thus sketched the general distribution of the fauna, it remains to point out the principal features of each of them.

142 *Arctic Fauna.*—The predominant feature of the arctic fauna is its uniformity. The species are few in number, but, on the other hand, the number of individuals is immense; we need only refer to the clouds of birds which hover upon the islands and shores of the north:—the shoals of fishes—the salmon among others, which throng the coasts of Greenland, Iceland, and Hudson's Bay. The same uniformity appears in the form and colour of the animals. There is not a single bird of brilliant plumage, and not a fish with varied hues. Their forms are regular, and their tints as dusky as the northern heavens. The most conspicuous animals are the white bear, the moose, the rein-deer, the musk ox, the white fox, the polar hare, the lemming, and various seals, but the most important are the whales, which it is to be remarked rank lowest among the mammals. Among the birds may be enumerated some sea-eagles and a few waders, with an immense number of other aquatic species, such as gulls, cormorants, divers, petrels, ducks, geese, &c., all belonging to the lowest order of birds. Reptiles are altogether wanting. The Articulata are represented by numerous marine worms, and by minute crustaceans of the orders Isopoda and Amphipoda. Insects are rare and of inferior types. Of the type of Mollusks, there are Acephala, particularly Tunicata, fewer Gasteropods, and very few Cephalopods. Among the Radiata are a great number of jelly-fishes, particularly the Beröe; and to conclude with the Echinoderms, there are several star-fishes and Echini, but few Holothuriæ. The class of Polypi is very scantily represented, and those producing stony corals are entirely wanting.

This assemblage of animals is evidently inferior to the other faunas, especially to those of the tropics. Not that there is a deficiency of animal life; for if the species are less numerous, there is a compensation in the multitude of individuals, and also in this other very significant fact, that the largest of all animals, the whales, belong to this fauna.

It has already been said that the arctic fauna of the three continents is the same; its southern limit, however, is not a regular line. It does not correspond precisely with the polar circle, but rather to the isothermal zero, that is, the line where the average temperature of the year is at 32° of Fahrenheit. The course of this line presents numerous undulations. In general, it may be said to coincide with the appearance of trees, so that it passes where forest vegetation succeeds the vast arid plains, the barrens of North America, or the tundras of the Samoyedes. The uniformity of these plains involves a corresponding uniformity of plants and animals. On the North American continent, it extends much farther southward on the eastern shore than on the western. From the peninsula of Alashka it bends northwards towards the Mackenzie, then descends again towards the Bear Lake, and comes down to near the northern shore of Newfoundland.

143 *Temperate Faunas.*—The faunas of the temperate regions of the northern hemisphere are much more varied than that of the arctic zone. At its northern margin, the leaves, excepting those of the pines and spruces, fall

on the approach of the cold season, and vegetation is arrested for a longer or shorter period. Insects retire, and the animals which live upon them no longer find nourishment, and are obliged to migrate to warmer regions, on the borders of the tropics, where on the ever verdant vegetation they find the means of subsistence.

Some of the herbivorous Mammals, the bats, and the reptiles which feed on insects, pass the winter in a state of torpor, from which they awake in spring. Others retire into dens, and live on the provisions they have stored up during the warm season. The Carnivora, the Ruminants, and the most active portion of the Rodents, are the only animals that do not change either their abode or their habits. The fauna of the temperate zone thus presents an ever-changing picture, which may be considered as one of its most important features, since these changes recur with equal constancy in the Old and the New World.

Taking the contrast of the vegetation as a basis, and the consequent changes of habit imposed upon the denizens of the forests, the temperate fauna has been divided into two regions, a northern one, where the trees, except the pines, drop their leaves in winter, and a southern one, where they are evergreen. Now as the limit of the former, that of the deciduous trees, coincides, in general, with the limit of the pines, it may be said that the cold region of the temperate fauna extends as far as the pines. In the United States this coincidence is not so marked as in other regions, inasmuch as the pines extend into Florida, while they do not prevail in the western states; but we may reckon as belonging to the southern portion of the temperate region, that part of the country south of the latitude where the Palmetto or Cabbage tree (*Chamærops*) commences, nearly all the states to the south of North Carolina; while the states to the north of this limit belong to the northern portion of the temperate region.

This division into two zones is supported by observations made on the maritime faunas of the Atlantic coast. The line of separation between them, however, being influenced by the Gulf Stream, is considerably farther to the north;—namely, at Cape Cod. It has been ascertained, that of one hundred and ninety-seven Mollusks inhabiting the coast of New England, fifty do not pass to the north of Cape Cod, and eighty-three do not pass to the south of it; only sixty-four being common to both sides of the Cape. A similar limitation of the range of fishes has been noticed by Dr. Storer, and Dr. Holbrook has found the fishes of South Carolina to be different from those of Florida and the West Indies. In Europe, the northern part of the temperate region extends to the Pyrenees and the Alps; and its southern portion consists of the basin of the Mediterranean, together with the northern part of Africa, as far as the desert of Sahara.

A peculiar characteristic of the faunas of the temperate regions in the northern hemisphere, when contrasted with those of the southern, is the great similarity of the prevailing types on both continents. Notwithstanding the immense extent of country embraced, the same stamp is everywhere exhibited. Generally the same families, frequently the same genera represented by different species, are found. There are even a few species of terrestrial animals regarded as identical on the continents of Europe and America, but their supposed number is constantly diminished, as more accurate observations are made. The predominant types among the Mammals are the bison, deer, ox, horse, hog, numerous Rodents, especially squirrels and hares, nearly all the Insectivora, weasels, martins, wolves, foxes, wild cats, &c. On the other hand, there are no Edentata, and no Quadrumana, with the exception of some monkeys on the two slopes of the Atlas. Among birds there is a multitude of climbers, passerine, gallinaceous, and rapacious birds. Of reptiles there are lizards and tortoises, of small or medium size, serpents, and many batrachians, but no crocodiles. Of fishes there is the trout family, the cyprinoids (carps), the sturgeons, the pikes, the cod family, and especially the great family of herrings and scomberiods, to which latter belong the mackerel and the tunny. All classes of the Mollusks are represented; though the Cephalopods are less numerous than in the torrid zone. There is an infinite number of Articulata of every type as well as numerous Polyps, though the true corals do not appear abundantly.

On each of the two continents of Europe and America, there is a certain number of species which extend from one extreme of the temperate zone to the other. Such, for example, are the deer, the bison, the cougar, the flying squirrel, numerous birds of prey, several tortoises, and the rattlesnake in America; and in Europe the brown bear, wolf, swallow, and many birds of prey. Some species have a still wider range, like the ermine, which is found from Bhering's Straits to the Himalayan Mountains, that is to say, from the coldest regions of the arctic zone, to the southern confines of the temperate zone. It is the same with the musk-rat, which is found from the mouth of Mackenzie's River to Florida. The field mouse has an equal range in Europe. Other species, on the contrary, are limited to one region. The Canadian elk is confined to the northern portion; and, on the other hand, the prairie wolf, the fox-squirrel, the bassaris, and numerous birds, never leave the southern portion.*

In America, as in the Old World, the temperate fauna is further subdivided into several districts, which may be regarded as so many zoological provinces, in each of which there is a certain number of animals differing from those in the others, though very closely allied. Temperate America presents us with a striking example in this respect. We have, on the one hand—

I. The fauna of the United States, properly so called, on this side of the Rocky Mountains.

II. The fauna of Oregon and California, beyond those mountains.

Though there are some animals which traverse the chain of the Rocky Mountains, and are found in the prairies of the Missouri, as well as on the banks of the Columbia, as for example, the Rocky Mountain deer (*Antilope furcifer,*) yet if we regard the whole assemblage of animals, they are found to differ entirely. Thus, the rodents, part of the ruminants, the insects, and all the mollusks, belong to distinct species.

The faunas or zoological provinces of the Old World which correspond to these are—

I. The fauna of Europe, which is very closely related to that of the United States proper.

II. The fauna of Siberia, separated from the fauna of Europe by the Ural Mountains.

III. The fauna of the great Asiatic table-land, which, from what is as yet known of it, appears to be quite distinct.

IV. The fauna of China and Japan, which is analogous to that of Europe in the birds, and to that of the United States in the reptiles, as it is also in the flora.

Lastly, it is in the temperate zone of the northern hemisphere that we meet with the most striking examples of those local faunas which have been mentioned above. Such, for example, are the faunas of the Caspian Sea, of the Steppes of Tartary, and of the Western Prairies.

The faunas of the southern temperate regions differ from those of the tropics as much as the northern temperate faunas do; and like them, also, may be distinguished into two provinces, the colder of which embraces Patagonia. But, besides differing from the tropical faunas, they are also quite dissimilar to each other on the different continents. Instead of that

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* The types which are peculiar to temperate America, and are not found in Europe, are, the opossum, several genera of insectivora, among them the shrew-mole, (Scalops aquaticus,) and the star-nose mole, (Condylura cristata,) which replace the mygale of the Old World; several genera of rodents, especially the musk-rat. Among the types characteristic of America must also be reckoned the snapping-turtle among the tortoises; the menobranchus and menopoma among the salamanders; the garpike and amia among the fishes; and, finally, among the crustacea, the limulus. Among the types which are wanting in temperate America, and which are found in Europe, may be cited the horse, the wild boar, and the true mouse. All the species of domestic mice which live in America have been brought from the Old World.

general resemblance which we have noticed between all the faunas of the temperate zone of the northern hemisphere, we find here the most complete contrasts. Each of the three continental peninsulas which jut out southerly into the ocean represents, in some sense, a separate world. The animals of South America, beyond the tropic of Capricorn, are in all respects different from those at the southern extremity of Africa. The hyenas, wild boars, and rhinoceroses of the Cape of Good Hope have no analogues on the American continent; and the difference is equally great between the birds, reptiles, and fishes, insects and mollusks. Among the most characteristic animals of the southern extremity of America are peculiar species of seals, and especially, among aquatic birds, the penguins.

New Holland, with its marsupial mammals, with which are associated insects and mollusks no less singular, furnishes a fauna still more peculiar, and which does not approach those of any of the adjacent countries. In the seas of that continent where everything is so strange, we find the curious shark, with paved teeth and spines on the back (Cestracion Philippi), the only living representative of a family so numerous in former zoological ages. But a most remarkable feature of this fauna is, that the same types prevail over the whole continent, in its temperate as well as its tropical portions, the species only being different at different localities.

144 *Tropical Faunas.*—The tropical faunas are distinguished on all the continents by the immense variety of animals which they comprise, not less than by the brilliancy of their coverings. All the principal types of animals are represented, and all contain numerous genera and species. We need only refer to the tribe of humming-birds, which numbers not less than 300 species. But what is very important is, that here are concentrated the most perfect and also the oddest types of all the classes of the Animal Kingdom. The tropical region is the only one occupied by the quadrumana, the herbivorous bats, the great pachydermata, such as the elephant, the hippopotamus, and the tapir, and the whole family of edentata. Here, also, are found the largest of the cat tribe, the lion and tiger. Among the birds we may mention the parrots and toucans, as essentially tropical; among the reptiles, the largest crocodiles and gigantic tortoises; and finally, among the articulated animals, an immense variety of the most beautiful insects. The marine animals as a whole are equally superior to those of other regions; the seas teem with crustaceans and numerous cephalopods, together with an infinite variety of gasteropods and acephela. The echinoderms there attain a magnitude and variety elsewhere unknown; and lastly, the polyps there display an activity of which the other zones present no example; whole groups of islands are covered with coral reefs formed by those little animals.

The variety of the tropical fauna is further enriched by the circumstance that each continent furnishes new and peculiar forms. Sometimes whole types are limited to one continent, as the sloth, the toucans, and the humming-birds to America; the giraffe and hippopotamus to Africa; and again, animals of the same group have different characteristics, according as they are found on different continents. Thus the monkeys of America have flat and widely separated nostrils, thirty-six teeth, and generally a long prehensile tail. The monkeys of the Old World, on the contrary, have nostrils close together, only thirty-two teeth, and not one of them has a prehensile tail.

But these differences, however important they may appear at first glance, are subordinate to more important characters, which establish a certain general affinity between all the faunas of the tropics. Such, for example, is the fact, that the quadrumana are limited on all the continents to the warmest regions; and never, or but rarely, penetrate into the temperate zone. This distribution is a natural consequence of the distribution of the palms; for as these trees, which constitute the ruling feature of the flora of the tropics, furnish to a great extent the food of the monkeys on the two continents, we have only to trace the limits of the extent of the palms, to have a pretty accurate indication of the tropical faunas on all three continents.

The tropical fauna of Asia, comprising the two peninsulas of India and the isles of Sunda, is well marked. It is the country of the gibbons, the red ourang, the royal tiger, the gavial, and a multitude of peculiar birds. Among the fishes the family of Chetodons is most numerously represented. Here also are found those curious spiny fishes, whose intricate gills suggested the name (*Labyrinthici*) by which they are known. Fishes with tufted gills are more numerous here than in other seas. The insects and mollusks are no less strongly characterized. Among others is the nautilus, the only living representative of the great family of large chambered shells, which prevailed so extensively over other types in former geological ages.

The tropical zone of Africa is distinguished by a striking uniformity in the distribution of the animals, which corresponds to the uniformity of the structure and contour of that continent. Its most characteristic species are spread over the whole extent of the tropics; thus the giraffe is met with from Upper Egypt to the Cape of Good Hope. The hippopotamus is found at the same time in the Nile, the Niger, and Orange River. This wide range is the more significant as it also relates to herbivorous animals, and thus supposes conditions of vegetation very similar over wide countries. Some forms are nevertheless circumscribed within narrow districts, and there are marked differences between the animals of the eastern and western shores. Among the remarkable species of the African torrid region are the baboons, the African elephant, the crocodile of the Nile, a vast number of antelopes, and especially two species of ourang-outang, the chimpanzée and another large and remarkable animal of the same kind, recently described by Drs. Savage and Wyman. The fishes of the Nile have a tropical character as well as the animals of Arabia, which are more allied to those of Africa than to those of Asia.

The large island of Madagascar has its peculiar fauna, characterized by its makis and its curious rodents. It is also the habitat of the aya-aya. Polynesia, exclusive of New Holland, furnishes a number of very curious animals, which are not found on the Asiatic continent. Such are the herbivorous bats and the galeopithecus, or flying maki.*

Several well marked faunas may be distinguished in the tropical part of the American continent—namely,

I. The fauna of Brazil, characterized by its gigantic reptiles, its monkeys, its Edentata, its tapir, its humming-birds, and its astonishing variety of insects.

II. The fauna of the western slope of the Andes, comprising Chili and Peru; and distinguished by its llamas, vicunas, and birds, which differ from those of the basin of the Amazon, as also do the insects and mollusks.

III. The fauna of the Antilles and the Gulf of Mexico. This is especially characterized by its marine animals, among which the manatée is particularly remarkable; an infinite variety of singular fishes, embracing a large number of Plectognaths; also Mollusks, and Radiata of peculiar species. It is in this zone that the *Pentacrinus caput-medusæ* is found, the only representative in the existing creation of a family so numerous in ancient epochs, the Crinoidea with a jointed stem.

The limits of the fauna of Central America cannot yet be well defined, from want of sufficient knowledge of the animals which inhabit those regions.

145 *Special Distribution of* QUADRUMANA.—In addition to the facts already given with regard to the various faunas in different parts of the

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* For the whole of this account of the distribution of the faunas, the author is indebted to an excellent abstract given by Prof. Agassiz, in his *Principles of Zoology*, recently published in America. The above five sections are adopted with little change from that work, chapter xiii.

world, it is desirable that we should consider also the special distribution of various races and natural tribes of animals. Of those which are calculated to give useful information of this kind, the great division of Vertebrata includes by far the larger number, and we now proceed to explain in what manner the class of Quadrumana is constituted with reference to climate and position.

Of the Quadrumana there are two subdivisions, the *Simiæ*, or monkeys, and the *Prosimiæ*, or makis. Of the former there are two families, the one having oblique and wide set nostrils and a human-like system of teeth, and characteristic of the Old World; and the other having nostrils placed at the side and wide asunder, with three false grinders on each side of both jaws, found only in America. There are in all one hundred and seventy described species, of which seventy-nine belong to the former and ninety-one to the latter country. There are thirty-two species of makis, making in all two hundred and two described Quadrumana.

With regard to the distribution of these two hundred and two species, we find that the apes are concentrated in countries under the equator, and there have their maximum. Of the three equatorial regions of Asia, Africa, and America, that of America (Brazil) has by far the greatest number of species, the amount being nearly double that of the continents of the Old World. Probably the greatest number of species of apes occur in the Silvas, on the banks of the Amazon, whence they extend to the eastern declivity of the Andes; they do not, however, cross the chain, since, on the whole western side of the Cordilleras, from Panama to Chili, only one or two species of the spider-monkey (*Ateles*) occur, and these are confined to Peru. Not only is the maximum of all the apes of the New World found in Brazil, but the maximum of each single genus also occurs there.

Of nine genera of monkeys found in the Old World, five are common to Asia and Africa. Four of these (the baboons, magots, macacos, and long-tailed monkeys, *Cercopithecus*) belong to the group of tailed monkeys, and the other (the Orangs) to the tailless monkeys. Of the other four genera the tailed gibbons are found only in Sumatra, and the solemn apes (*Semnopithecus*) occur pretty widely distributed in the islands of the Indian Archipelago, and are met with also in India and China, but nowhere in Western Asia or Africa. The whole group of the gibbons corresponds pretty nearly in distribution with that of the solemn apes, and the two groups are similarly limited, while thumbless apes (*Colobus*) are strictly limited to Africa, and chiefly confined to about sixteen degrees on each side of the equator.

The Baboons (*Cynocephalus*) are large, ferocious, and dangerous apes, attaining the size of a wolf, and remarkable for their canine physiognomy, whence their name has been derived, (κυνη, *cynè*, dog, κεφαλη, *cephalè*, head.) There are two groups of them—viz., the baboons proper and the mandrills. One species of the former is nearly confined to the Cape of Good Hope, another to the vicinity of the Red Sea, another to Northern and Central Africa, and another to Asia (East Indian Islands). The mandrills are exclusively met with in Central Africa.

The Magots are represented in North Africa and Europe by the Barbary ape, and in Sumatra by another species. The Barbary ape is not indigenous in Europe, but has migrated from Ceuta to Gibraltar, the only European locality in which it occurs.

There are two divisions of macacos—the long-tailed and short-tailed. They are both widely spread, but the second division occurs only in Asia, inhabiting Hindustan, Ceylon, Java, and Sumatra. The species of the former abound in the East Indian Islands and occur also in Africa.

The Thumbless apes (*Colobus*) form a peculiar African group of the Asiatic genus *Semnopithecus*, (Solemn apes). The latter are long-tailed and have a slender body; they are mild, intelligent, and slow. They abound in India, Ceylon, and the South-eastern Archipelago, and one species extends into China, Cochin China, and the Malay peninsula, where its flesh is highly prized as an article of food. The African thumbless apes have a singular head of hair, and there are several (eight) species of them.

The Long-tailed monkeys (*Cercopithecus*) are chiefly African, where they are described as being singularly abundant. The proper habitat of the genus is Western Africa, but six species occur in Asia, one of which is common to the two continents. One species reaches far south in Africa, and another inhabits the island of Mauritius.

The Tailless monkeys are of two groups, the long-armed apes (gibbons) and the orangs. The former inhabit only the most secluded parts of India and the Eastern Archipelago; the latter are found both in Asia and Africa, but are limited to about thirteen degrees latitude on each side of the equator, and occur chiefly in the interior of the country.

The Monkeys of the New World differ remarkably from those of the Old, especially in their smaller size and less ferocious manners, in the possession of naked callosities, and in the want of cheek pouches. They form two groups, and include, as we have already said, a very large number of species. The monkeys of the first group all possess prehensile tails; they include the *howlers*, (nine species,) the *spider monkeys*, (two,) the *gluttonous monkeys*, (two,) and the *weepers*, (twenty-three.) The species of the first genus are of large size and have the widest circle of distribution, being found as far north as Panama, and extending also to the south polar limit of the whole race. The spider monkeys inhabit chiefly Brazil and Guiana; they are generally mild, timid, melancholy, and inactive. The gluttonous monkeys are strictly confined to the tropical countries in the interior of South America, and the weepers, although found in greatest numbers in Guiana, extend southwards to the tropic of Capricorn; they are mild, quick and lively in their movements, and excellent climbers. The second group of American monkeys are chiefly Brazilian, and they generally have large tails and bushy hair.

The *Makis* include thirty-two species, of which fourteen are *Lemurs*, and six *Loris*. The Lemurs are exclusively confined to Madagascar and the adjacent islands, and so are also another group (*Lichanotus*), the largest of the tribe, attaining the size of a baboon. The Lorises are distributed through Asia, and are remarkable for their nocturnal habits, and large sparkling eyes.

Among the Monkeys of the Old World, one of the solemn apes (*Semnopithecus entellus*) ascends to the greatest height attained by the Quadrumana, and where there is wood, individuals are found on the slopes of the Himalayan Mountains, 13,000 feet above the sea. In Africa the *Macacus montanus* is found in Abyssinia, to the height of 8000 feet, and one of the howling monkeys of America occurs on the eastern side of the Andes, at more than 11,000 feet elevation.

146 *Distribution of* CARNIVORA.—The Carnivora are so important, as well by their number as in their distribution, that they require to be considered in some detail. The families of Carnivora are five—four of them terrestrial, and the fifth marine. They are divided into sixty-six genera, and about five hundred and twenty-six species; of these the first family, or bats (CHIROPTERA), includes two hundred and twenty-four species; the insect-eaters (INSECTIVORA), sixty-one; the PLANTIGRADA, thirty-four; and the DIGITIGRADA, one hundred and ninety-five; the remainder are AMPHIBIA.

The distribution of the Bats is most considerable within the tropics, where there are seventy-two species in Asia, forty-one in Africa, and fifty-five in America, without including the species in New Guinea and the islands of the Pacific, which number twenty-five species. The most extensive genus (that including the common bats of Europe) is also the most widely distributed, ranging from the Arctic circle to the extremity of Australia, and also into South America.

The *Insectivora* are pretty generally distributed throughout the great continents, but are entirely absent in the islands of the Pacific Ocean, including Australia, and in South America, below the tropics. The greatest number of species (twenty-five) occur in tropical Africa, but there are fifteen in tropical Asia, and four in tropical America. The shrews are found throughout, and the hedge-hogs almost so; the moles are pretty general in north, temperate, and arctic climates, but are almost entirely absent in the tropics. Generally, the Insectivora are remarkable in not following the general law with regard to Carnivora, that of increasing and attaining all their maxima in tropical climates.

The *Plantigrades*, like the Insectivores, are absent in the islands of the Pacific, in Australia, and temperate South America, but differ remarkably in their tropical distribution, only two species occurring in Central Africa, while twelve tropical species are American, and eleven Asiatic. The bears are the more generally distributed, and are found throughout; the gluttons present the same number of species within the tropics and in the Arctic circle, but are, with one North American exception, entirely absent in the temperate climates.

The *Digitigrades* are met with everywhere, the dogs being the most widely distributed; the cats are next in importance in this respect (being absent in Australia and the Pacific Islands), and then the martins and otters must be mentioned. This family, although not so numerous as that of the bats, is the most important, since it contains the fiercest and strongest of all the Carnivora. The most interesting groups among them are—*Canis* (dog), and *Felis* (cat)—the former of which, in some form or other, has representatives in every country from the Arctic Sea to the southernmost islands in the Pacific, and in the Old as well as in the New World. Some particular species are also very widely spread, the wolf occupying both continents, from the Arctic Circle to the north coast of Africa and the Isthmus of Panama, extending eastwards into India, and westwards to the western shores of America. The fox ranges over the greater part of Europe, and almost the whole of northern Asia; the jackal, the representative species in Africa, extends from the Senegal to India, and from Abyssinia to southern Russia. The whole tribe is, however, remarkably poor in species in India beyond the Ganges, and also in the Indian Archipelago, which, in other respects is rich in Carnivora.

The genus Felis is found in all parts of the world, except in the islands of the Pacific, Japan, and the Philippines, and the vast expanse of Australia. The species inhabiting America differ greatly in appearance from those of the Old World, and are generally smaller in size. They are also confined to the eastern side of the Andes. The lion is spread over almost the whole of Africa, from the Cape of Good Hope to Barbary, but is confined in Asia to a much smaller region, not extending beyond lat. 32° north, and chiefly met with in the jungle countries of India, and the borders of the Euphrates. The puma, the lion of America, has a far wider range, extending from Patagonia, in lat. 54° South, to California on the one side, and the Canadian lakes on the other, in lat. 50° north, a distance of 7000 miles. The tiger, more active than the lion, and nearly equal in strength, is very differently distributed, ranging through almost the whole of India, Siam, and China, extending northwards far into Central Asia, and southwards into Sumatra and Java. The jaguar, or American tiger, has its principal habitat in Brazil and Paraguay, but reaches southwards only to the latitude of Chiloe, and does not extend northwards beyond the borders of Mexico.

The vertical distribution of the Carnivora is, of course, very different in different zones of latitude. In Europe, in the Alps, the bats range to about 8250 feet, several species occurring at that elevation. The hedge-hog, amongst Insectivora, is met with at the same height, but the shrews a little lower. The black and brown bear are found in the Alps, between 5000 and 8000 feet, and the Pyrenean bear at nearly 9000 feet. The stoat (ermine), amongst Digitigrades, has been met with at the height of 9600 feet. The martin, the wolf, the otter, the wild cat, and the lynx ascend in the Alps to about 8000 feet, and in the Pyrenees a little higher. In Northern Europe, the glutton and the wolf ascend the highest of the Scandinavian Alps, from which the latter animal frequently descends to the plains, when the mountains are covered with snow.

In tropical Asia, one species of bat ascends to the height of 9600 feet; a species of weasel occupies a height of 8000 feet; the tiger ranges, in Java and Sumatra, from the sea-shore to nearly 4000 feet above it, and on the continent of India pursues its prey to an elevation of 9600 feet, where vegetation loses its tropical character. This animal, as well as the leopard and panther, frequent the naked, woodless, table-lands of Thibet, at a height equivalent to that of Mont Blanc. In tropical Africa, the lion of the Cape dwells on table-lands, at an average height of nearly 5000 feet above the sea; and, at the same elevation, one of the hyenas (*H. venatica*) pursues not only the antelopes, but even the lion and panther, attacking them in herds, and overpowering them by numbers. In tropical America, the bear lives at 16,000 feet above the sea, on the confines of the snow-line; the puma ranges in the Cordilleras of Chili, to the height of 11,000 feet (also close to the snow), whilst, in Peru, the jaguar scarcely attains the height of 3000 feet, although the ocelot is met with at double that elevation.

The *Amphibia*, being marine animals, obey laws of distribution very distinct from those to which the land quadrupeds are subject, and may be more conveniently considered afterwards.

147 *Distribution of* RODENTIA.—There are in all six hundred and four species of Rodents recognised and described, which are grouped into ninety-five genera, and these again into four principal families—namely, the squirrel family (including also the beaver), the rat family, the porcupine family, and the hare family. In all these, the species of the same group generally have a wide range in the same zones of climate, except when they are inhabitants of high ridges of mountains, in which case they follow the course of the mountains, even when, as in the Andes, these run from north to south. There are also examples of groups, for the most part confined to high latitudes, but re-appearing in low latitudes at considerable elevations. It is also worthy of remark, that the great mass of the South American Rodents belong to a group, naturally distinct from and of lower organization than the mass of the species in the Old World, and the northern parts of the New.

Of the squirrel family, (153 Species,) as many as ninety species are true squirrels, of which thirty-two are East Indian, twenty-four North American, twelve from Asia, (excluding the East Indies,) eleven Central and South American, and only two European. Of the genus *Pteromys*, (flying squirrels,) almost all the species are confined to Eastern Asia and the Indian Islands, and the rest are North American. Africa is remarkably poor in all kinds of squirrels, having only eighteen species, sixteen of which are true squirrels, and two referred to a genus which has no other representatives. The Beaver, the only other well-known and interesting rodent of this family, except the marmot, presents two species, the European and the North American beaver. The former is found in the rivers of temperate and Northern Europe and Asia, between latitude thirty-six degrees and sixty-seven degrees; the latter ranges on both sides of the continent of North America, but chiefly on the eastern side, between the northern limits of tree vegetation, and the confluence of the Ohio with the Mississippi river. The Marmots are confined to high mountain localities, or nearly so, and are found in the Alps, in Poland, and Russia, in Europe; in the hilly region of Nepaul and Thibet, and also in the valley of Cashmere, in Asia; and in America, from the sixtieth parallel of latitude, on the Rocky Mountains as far as Texas.

The Rat family contains 306 acknowledged species, 195 occurring in the Old World, and 114 in the New. Of all the genera, the common rat is at once the most numerous and the most widely distributed; its seventy-five species being distributed in pretty equal proportions through every zoological region on the globe; one of them, the common brown rat, occurring in all parts of the world; others, such as the black rat, the field mouse, and the harvest mouse, extend through Europe; the Barbary mouse, and another species, through North Africa; several others occur in South Africa, and others in various parts of Asia. The species peculiar to Central and South America are, however, very few, even these being doubtfully ascribed to the genus.

Of the other genera of this family, the common dormouse (*Myoxus*) occur throughout the southern and western parts of temperate Europe, and other species in Africa and Asia Minor. The *Jerboa* has a range extending from North Africa into Eastern Europe, and Western Asia. The *Hamster* is another animal limited in pretty much the same way, but not extending to Africa. Besides the recognised animals of this group, there are a number of species found in South America, which have been doubtfully ascribed to it, and require further examination. The group of Voles (*Arvicola*) are also interesting, and widely spread. The water vole, or water rat of England, is found throughout Europe and Northern Asia, extending eastwards as far as the river Lena, in Siberia, and northwards to the Arctic Ocean. Other species are found in most of the countries of Europe and Northern and Western Asia, and there is also a considerable number peculiar to North America. The *Lemming* is a curious genus, confined to the polar regions of both hemispheres, and the countries immediately adjacent.

The third family of Rodents includes the common Porcupine of Europe, and some other genera spoken of under the same name, such as the Canada porcupine, and the prehensile porcupine. The first named is indigenous in Southern Europe, Asia Minor, and Northern India, but it occurs also in Barbary, and re-appears at the Cape of Good Hope. The Canada porcupine is a widely spread North American representative, and the prehensile porcupine extends from the north coast of South America, as far south as Bolivia. Belonging to the same family, we have also the *Agouti*, a well known Brazilian genus, and the spotted cavy, found throughout the whole of South America, as far down as Paraguay. The *Chinchilla*, the *Biscacha*, the Guinea pig, the *Capybara*, and many other animals are also referred to it; and, indeed, in the New World, we have as many as seventy-seven species, instead of the six found in the Old World. This important fact in the distribution of the Rodents is well worthy of observation.

The fourth and last family of Rodents presents only two genera, the Hare and the *Lagomys*. The varieties of the common hare and rabbit, and the species of the same genus most nearly allied, may be said to inhabit the north temperate portions of the eastern hemisphere generally, some being confined to the warmer parts, but others ranging quite up to the Arctic Circle. Some species occur also in India, others in North Africa and Egypt, others in Asia Minor, Syria, and Arabia, and others again at the Cape of Good Hope. There are in all twenty-two species distributed in this way, and fourteen in various parts of North America, from the Arctic Circle to Texas. One species only is met with in South America, and this ranges throughout Brazil, and extends to Peru, Bolivia, and Paraguay. The genus Lagomys, is, with one exception, confined to the Old World, and chiefly to the northern extremity of it, although an American species is found on the Rocky Mountains, between the forty-second and sixtieth parallels.

148 *Distribution of* RUMINANTIA.—The animals of this order, which is one of the most natural and best defined of all the primary groups of quadrupeds, are distinguished from all others by the existence of four stomachs, arranged for the act of ruminating or 'chewing the cud.' They are all essentially herbivorous; they have cloven feet; and it is only amongst them that species are met with whose foreheads are armed with true horns.* There are in all nine genera, represented by the *Camel*, the *Llama*, the *Musk-deer*,

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* The horn of the rhinoceros consists of parallel horny fibres, scarcely indicated on the skull, and belonging only to the skin.

the *Deer*, the *Giraffe*, the *Goat*, the *Sheep*, and the *Ox*, respectively: they are most numerous near the equator, but are distributed over all latitudes in the northern hemisphere, as far as the Arctic Circle. They are, however, totally absent in Australia, New Guinea, the South Sea Islands, and Madagascar.

The greatest number of species of Ruminants occur in Asia and Africa, each of these countries possessing more than one-third of all the species, so that, on the whole, the Old World possesses as many as 128 species, while in the two Americas there are only twenty-three species.

Of the particular genera, the Camel is a native of Asia, and now extends over Arabia, Syria, and Asia Minor, to the foot of the Caucasus, the south of Tartary, and India. It extends also in Africa, from the Mediterranean to the Senegal, and from Egypt and Abyssinia to Algiers and Morocco, and it abounds in the Canary Islands. The Bactrian camel, distinguished by its two humps, its rougher and shaggier hair, and stronger and more muscular frame, is almost unknown in South-western Asia, but abounds in the countries north of the Taurus and the Himalayan Mountains, extending, it is said, to the borders of China. The Llamas, the camels of the New World, present three species, differing from the true camels, by being much smaller, and having no hump on the back. They are chiefly distributed on the western side of the Andes, extending from Venezuela and New Granada, through Peru, Bolivia, and Chile, into Patagonia, and even to the wooded islands of Tierra del Fuego.

The Musk-deers, of which there are seven species, are distributed in various parts of Asia, chiefly south of the Himalayans, but two species are found in Africa. The whole group is distinguished by the absence of true horns. The true deers have solid horns or antlers; they include on the whole thirty-eight species, twenty-eight of them being found in the Old World, and of these, twenty-one in the East Indies. The largest of the genus, the elk or moose deer of America, inhabits the colder regions both of the Old and New World; the European elk, a distinct species, is found in the forest regions of Scandinavia, Eastern Prussia, Poland, Lithuania, and Russia, extending eastwards into Asiatic Tartary, and southwards to the Caucasus; the reindeer has its southernmost limit in America, in latitude fifty degrees north, but is most abundant between 63° and 66° north latitude. In Asia it traverses Siberia and Kamschatka, and in Europe is found in Iceland, Spitzbergen, Scandinavia, and Northern Russia, but chiefly in Finmark and Lapland.

The Fallow-deer inhabits central Europe, as far as fifty-three degrees north latitude, but extends also to the north of Persia and China, and is found in the northern part of Africa, as far south as Abyssinia. The common stag or red-deer is also a native of the temperate countries of Europe, but ranges ten degrees further north than the fallow-deer, and has not been found south of the Caucasus. It occurs in Siberia, from the Altai Mountains to the Lena River. The roebuck is also widely distributed in Europe, as far as fifty-eight degrees north latitude, and in Asia, eastwards to the River Lena, and southwards to Peru; it is common in the north of England, and in the north of Scotland, but is unknown in Ireland. In North America there are six species, and in Central and South America eight, one species being common to the two Americas. The most remarkable is the Virginian deer, which ranges from Canada, as far south as Louisiana.

The Giraffe is an isolated genus exclusively confined to Africa. There are two species, one inhabiting Nubia, Abyssinia, and the countries near Lake Tchad, the other a southern species, found in south lat. 29°, near the Orange and Lion Rivers. Africa is also the head-quarters of the Antelopes, containing thirty-four species, while Asia has only ten, Europe two, and America one. The European antelope, the *Chamois*, inhabits the alpine districts of Europe and Western Asia, being found in the Alps, Pyrenees, the Tatra, the mountains of Greece, the Caucasus, and the Taurus. The Goats, like the European antelopes, inhabit alpine countries, and of these the *Ibex* is well known, and ranges even to a greater height than the chamois, being found occasionally even above the snow line. The greatest number of species of the goat family are Asiatic, and only two are met with in the New World.

The Sheep are considered to have inhabited originally Western Asia. There are in all twenty-one species, thirteen of them Asiatic (excluding the East Indies), and five East Indian, there are also two in the Rocky Mountains of North America. In a domesticated state they have been introduced into most parts of the civilized world. The Bovine tribe (oxen), of which there are thirteen species, comprise the largest of ruminating animals, and are widely distributed over most countries of the globe. The Buffalo, long known as a domesticated animal in India, has spread westwards to the western extremity of Europe, and eastwards to the islands in the Pacific Ocean. The Cape Buffalo is a much more ferocious animal, wandering in large herds over extensive districts in South Africa. The two American species, the bison and the musk ox, are both confined to North America, the former extending from New Mexico and California to about 64° north latitude, while the latter is peculiar to the frozen regions of the continent, its southern range commencing where the bison terminates, and extending thence over the barren regions of the Polar districts to Melville Island, thus attaining with the rein-deer the highest latitude of any known species of ruminant.

The vertical distribution of ruminants is not uninteresting, the Chamois and Ibex reaching in the Alps to the snow line (8900 feet), while oxen graze and sheep pasture within a thousand feet of this elevation. The common stag in the same parts of the country reaches only to 7000 feet, and the fallow-deer to 6000. In the table-lands of Central Asia, the goats and sheep not only reach the height of from 10,000 to 16,000 feet, but one species is described as bounding lightly over the encrusted snows of the higher ridges of the Himalayan Mountains, where its human pursuers find it difficult to breathe. Another species, the *Yak*, seems actually limited to districts where the temperature is below that of the freezing point of water, and even the Bactrian camel attains in the table-lands of Central Asia a height at from 3000 to 5000 feet above the sea. In South America, the Llama inhabits the bleak and rocky precipices of the Andes and regions bordering on the limit of perpetual snow. In the cold climate of Patagonia these animals approach the vicinity of the sea, but further north large herds attain (as on Chimborazo) a height of 15,800 feet, and on the Bolivian Andes an elevation of 18,000 feet.

149 *Distribution of the* PACHYDERMATA.—Of this family there are nine genera containing thirty-nine species. Only one species (*Sus*—the swine) is indigenous in Europe, while nineteen are Asiatic, twenty African, and seven American. Besides the Swine, the Asiatic genera includes the Elephant, Rhinoceros, Tapir, and Horse, and to these in Africa are added the Hippopotamus, Hyrax, and Phascochœrus, while in America we have only the Peccaries and Tapirs. The animals of this order are not only few in number, but much smaller in size in the New World than in the Old. In North America they are totally absent, and so also are they in Australia. On the other hand, in Africa they are singularly abundant, and highly characteristic.

If we refer to the particular genera, we find the Elephant inhabiting the whole of the peninsula of India, the Birman Empire, and Siam, extending also to Cochin China. It ascends the Himalayan Mountains to the height of 6000 feet, and reaches southwards to the extremity of Sumatra, although it has never yet been proved indigenous in Java or Borneo. The African species reaches from the Mountains of the Moon nearly to the Cape of Good Hope, thus ranging in the western part of the Old World from 31° south latitude to 13° north, and in the eastern part from 6° south latitude to about 30° north. The Hippopotamus at present extends from the Orange River, near the Cape of Good Hope, to the upper Nile in Dongola, and occasionall still farther north. The Rhinoceros is more subdivided into species than elephant or hippopotamus, there being four African and three Asiatic; it is confined to nearly the same limits as the elephant, but extends a little farther north into China, and also into Java. The common or one-horned African species, and the corresponding one-horned species in India, are the most widely distributed, the others are smaller and chiefly found in the interior of the country. The genus *Sus* (or swine) is distributed into three groups, the European-Asiatic, the Indian, and the South African. The first contains only the common swine, which ranges from the shores of the Atlantic to the Pacific, extending westwards from the borders of the Sahara to the Baltic provinces of Russia, and eastwards from the Gulf of Tonquin to Lake Baikal in Siberia. The other species are far more narrowly distributed, one of them forming a passage to the Tapirs, and another nearly confined to South Africa, and extending into Madagascar, where it is the sole representative of the whole tribe.

The *Hyrax* (daman) is a singular and interesting genus of pachyderms, approaching the rodents in some respects, and at present only known in South Africa, in the countries bordering the Nile, and in Syria. The *Phascochærus* (warthog) is also exclusively African, inhabiting the country between Abyssinia and the northern extremity of the Cape Colony, and rare even within these limits. The other Pachydermatous group of the Old World is that which includes the Horse, the Ass, and the Zebra. It is not possible now to determine the original limits of the true horse, though it appears to be a distinctly Asiatic species. The ass seems characteristic of Central Asia, and the zebra is peculiar to Africa, where there are several species ranging southwards as far as the Cape of Good Hope.

The only remaining Pachyderms are the *Peccaries* and *Tapirs*, the former absolutely confined to South America, the latter chiefly characteristic ot that continent, but not uncommon in the islands of the Asiatic Archipelago. The Peccaries inhabit dense forests, and extend from the peninsula of Yucatan in Central America to Paraguay, climbing the eastern slopes of the Andes to the height of six thousand feet. The common American tapir is met with from Nicaragua (latitude 14° north) to the Pampas of La Plata, in latitude 40° south, and ascends the Andes to as great a height as the peccaries. Another species inhabits chiefly the most elevated parts of the Andes of New Granada.

150 *Distribution of the Edentata and Marsupialia.*—Of the former of these remarkable groups there are six recognised genera, four of them confined to the New World, one occurring only in Africa, and one (*Manis*) reaching into Asia. South America contains three times as many species as all the remaining countries of the World, and is in every respect the metropolis of the order. We shall see also in a future chapter that this distribution has long obtained.

The principal genera of the Edentates are the *Sloths*, the *Armadillos*, and the *Ant-eaters*. The former ranges from the southern limits of Mexico as far south as Rio Janeiro; and from the eastern coast to the slope of the Andes there are four species, all inhabiting the trees of the gigantic and primeval forests of those countries. The armadillos, of which there are eleven species, range in like manner through Central and Southern America, they vary in their habits, living in the plains as well as on the table-lands, and extending into the lower regions of the Andes to the height of about 3000 feet. There is one remarkable and closely allied genus (*Chlamyphorus*) inhabiting Chili and La Plata, and interesting from the enormous strength exhibited in so small a frame. The American ant-eaters, the largest of the Edentata, are less widely distributed than the sloths and armadillos, both in vertical and horizontal space.

The Edentates of the Old World number only five species in all. The African genus includes one ant-eater (*Orycteropus*) very different from the American species, and extending from the Cape Colony to Congo. The *Pangolin*, or scaly ant-eater (*Manis*), has four species, and ranges from the

Senegal in Africa, in a narrow band southwards to the equator, occurring also in North-eastern India, and thence eastward to Formosa, and in the islands of Sumatra, Java, Borneo, and the Celebes.

As South America is the country of the Edentates, so on the continent of Australia and its adjacent islands we find the great majority of the Marsupial tribe, although of these also a few representative forms have been found in America. The whole order has been divided into eight families, which present a remarkable diversity of structure, and consequently of habit, some species amongst them being herbivorous, some carnivorous, and others insectivorous. All, however, present the striking peculiarity of the order—namely, the premature birth of the young, and the existence of a kind of bag or pouch, situated beneath the belly of the female to receive them at this period, and retain them for a considerable time even after they have grown to a large size.

The *Ornithorhynchus* and *Echidna*, two of the most remarkable animals known, form one group of the marsupials, and are almost confined to South-eastern Australia and Van Diemen's land. The *Kangaroo* family, which numbers not fewer than forty species, are very widely distributed in Australia and New Guinea, and have been said to occur in Java. The *Wombats*, of which there are two species, are found chiefly in the southern and eastern part of Australia and Van Diemen's land. The *Phalangers* are widely distributed not only in Australia but in New Guinea, and many of the Asiatic islands, extending even to the Celebes. The *Dasyuridæ* (including the *Thylacinus*, or 'Australian dog) are limited to New South Wales and Van Diemen's land, while the *Opossums* are an exclusively American family, extending from the southern limits of Canada to the thirty-sixth parallel of south latitude. They are nearly confined to the eastern side of the continent, and one, a Brazilian species, lives in the water. The whole number of species of marsupials may be estimated at not less than 126; and the group found in Australia is the more important from the absence in that country of other mammals, and the number of representative forms of various tribes which it includes.

151 *Distribution of* BIRDS.—Birds, like other Vertebrates, exhibit the greatest number of species in the tropical climates, with the partial exception, however, of the continent of Europe, which contains 490 species, while, although tropical America has 624, tropical Asia presents only 450, and Africa only 211. North temperate America affords in all 178 species, and the north frigid zone in America as many as 103. There are, also, other apparent anomalies when we examine the different orders in detail; as, for example, there are 186 European species of *Oscines* (singing-birds) and 112 of *Natatores* (swimmers), while in tropical America there are 319 of the former and only 26 of the latter group. Europe and tropical America possess the greatest number of birds of prey, and the climbers and songsters are most abundant in the latter country. Tropical Asia presents the greatest number of *Gallinaceæ*, and Europe the greatest number of waders and swimmers.

If we take the particular genera, we find amongst the birds of prey the Vulture tribe the most remarkable, and the largest of all flying birds. The habitat of the *Condor*, of which individuals have been found in the Andes of Quito measuring fifteen feet from tip to tip of the wings, is exclusively confined to the vicinity of the Andes, and breeds at an elevation of from 10,000 to 15,000 feet above the sea. Humboldt, on one occasion, saw this enormous bird floating over the summit of Chimborazo at an elevation of upwards of 22,000 feet. The species ranges from the Strait of Magalhaens to 7° north latitude. Of the other vultures several are American, and there are also species dispersed through Africa and India. The birds of prey of Europe include five vultures, thirty-four hawks, and fifteen owls, many of them extending into North Africa and Asia. The greater number of species occur in the south of Europe, and as many as twelve range through various parts of the Alps. These include one vulture, two eagles, five hawks, and four owls.

The order of climbing birds, including the parrots, cuckoos, king-fishers, and others, are chiefly confined to the tropical zone; but they also occur abundantly in the southern hemisphere, where they extend to very high latitudes, reaching even beyond New Zealand as far as Macquarie in latitude 56° south. In the northern hemisphere they attain in the United States the latitude of 42° north. Forty species are found in the tropical regions of South America, while only three inhabit the opposite coast of Africa. The Birds of Paradise, a small but very remarkable group, are limited to a few islands in the neighbourhood of New Guinea, migrating according to the monsoons. The Toucans, and some other groups, are also confined within very narrow limits. Of European climbers there are twenty-three species, some of them, as the Woodpecker and Hoopoe, ranging throughout the whole continent, but others more local. Eight of them inhabit or traverse the higher parts of the Alps.

Of the order of songsters (*Oscines*), the Humming-birds, the smallest and most brilliant of the whole tribe, are all natives of America, and chiefly of the tropical portions of that country, but they range to the height of 10,000 feet on the Andes, and have been met with breeding in the Island of Juan Fernandez (33½° S. latitude), and as far north as latitude 61° on the shores of Behring's Straits. Of the 186 species of this order found in Europe, as many as 100 belong to the typical genus from which the order has received its name, and which are all of them song-birds. Forty-three of these extend into Africa, and ten reach to tropical Asia; there are also ten European species of Larks; forty-three of Finches, of which one, the common Sparrow, extends over most parts of the known world; twenty-eight Nut-hatchers, including amongst them six species of *Corvus* (crow), and five species of Swallow. These are all of them pretty generally distributed throughout the country, and range also into the adjoining continents.

The gallinaceous birds are far more numerous in the Old World than the New, the greatest number of species (72) being found in tropical Asia, and some of these being now domesticated in almost every country. The Pheasant thus extends, in its natural distribution, from the Caucasus through Central Asia to China, and southwards as far as Java; the Peacock is a native of India; the Pigeons (of which six species are European) extend into the two great continents; and the Turkey is peculiar to the New World, its proper limits appearing to be from the Isthmus of Panama to the north-western extremity of the United States. It does not appear to be indigenous on the western side of the Rocky Mountains, or in South America. Only twenty-eight species of the order are found in Europe, and many of these are not natives; but the grouse, the pheasant, the common fowl, the pea-fowl, the partridge, and many others are of this kind, and are too well known to require further allusion. Two species of pigeon, four of grouse, and two of partridge, have been found amongst the higher passes of the Alps.

The order *Grallatores*, or waders, is most abundant in the north temperate zone, but by far the most remarkable species occur in tropical and southern countries—thus, the African and South-American *Ostrich*, and the Australian *Emu*, as well as the *Cassowary*, are amongst the most extraordinary, as they are the most gigantic of birds. The former (the ostrich) has a tolerably wide range, and has been met with to the height of 7000 feet, on the high plateau of the Uspallata Mountains, in South America. One South American species extends to 54° south latitude, and the African species ranges from the Cape of Good Hope to Barbary, and has extended as far as the southern declivity of the Caucasus, and the shores of the Black Sea. The most numerous European genus is that which includes the Snipes, of which there are thirty-eight species, sixteen of them extending into North Africa, and twenty-five into Siberia. The Ibis and the Flamingo are recognised species in Europe, but belong to Africa and Asia.

The *Natatores*, or swimming birds, including the ducks, pelicans, penguins, gulls, and many others, are, like the waders, more abundant in European than tropical latitudes. There are one hundred and twelve

European species, of which forty-four belong to the duck genus, and thirty-three to the gulls, of each of these more than half extending into Asia. The Eider-duck is an interesting and important species, chiefly inhabiting the shores of the Arctic Ocean, and the land immediately adjacent, extending in Europe to the Orkney Islands, and even into Germany, and in America to the latitude of New York.

The migration of birds is a fact in their natural history which fully accounts for the wide extent of country over which many species are found. Some proceed to very distant spots in search of food, or at the breeding season, and many of the sea-fowl are found over many thousand miles of ocean, and are rarely seen to rest, while other birds, although not naturally migratory, proceed from one spot to another on the occasional failure of food in their natural district. The habits of birds in migrating are very different, some going singly, some in small groups, others in flocks of many thousands. When in great multitudes, they generally have a leader, as in the case of the swallows and martins; but when the groups are smaller, the birds often fly in very regular order—wild geese, for example, in the form of a wedge. The swift, a remarkable bird in its power of sustaining rapid and long-continued flight, is said to proceed at the rate of one hundred miles per hour, and the wild duck and wild pigeon four or five hundred miles in a day. Migrating birds generally return to the same spot, within a few days of the same time of the year, and often occupy the same nest for successive years.

152 *Distribution of* Reptiles.—Of the existing orders of reptiles, the *Sauria*, including crocodiles and lizards, number two hundred and three species; the *Chelonia*, or tortoises, sixty-nine species; the *Serpents* two hundred and sixty-five species, and the *Batrachians* (frogs), one hundred and twenty species—making in all six hundred and fifty-seven. Of this number more than twice as many are found in the countries of the torrid zone than appear in temperate climates. The *Chelonia* are most numerous in the United States, where there are nineteen, in Brazil (fifteen), and in the Indian islands (thirty-three). In Africa (Barbary) there are six species, and in Europe, except in Italy and Turkey, only three in all. The *Sauria* include thirteen species of Crocodiles, nine of them American, and four Asiatic and African. The remaining Sauria are far more widely distributed in Africa and South America than in the rest of the world, Brazil being the richest in species, and containing in all as many as forty-two. *Serpents* are far the most abundant in the East Indies and in Central and South America, and most of all in the Island of Java, where no less than fifty-six species have been determined, while in the adjacent Island of Borneo there is not at present a single one known. The *Batrachians* are most numerous in Central and South America, but thirty-nine species are North-American, and twenty-three European. Asia, Africa, and Australia show a remarkable absence of the animals of this order. Generally, reptiles may be regarded as more limited to warm climates than any other animals, and better able from their structure, and the slowness of their circulation, to bear the extreme rigour of an excessive climate than the absence of hot summers that characterizes island countries.

Of the *Chelonians*, the common marsh tortoise of Europe attains the highest latitude, extending in Prussia to lat. 52° north, while a corresponding species in North America reaches to 50° north. Some of the sea-turtles have been met with in the northern hemisphere, even so far north as the Shetland islands (lat. 60° 30″), but the individual in question may probably have been drifted thither by storms, its usual range being only to the shores of France, to about the fiftieth parallel of latitude. The species thus observed (the hawk's-bill turtle), furnishes the horny plates usually known in commerce as tortoise-shell, but the principal fishery of these animals is in the Moluccas, and other islands of the Indian Archipelago, and the islands of the West Indies; the former, however, being the most important, since the shell is the most valuable. The green turtle, used for food, is a species inhabiting the tropical parts of the Atlantic Ocean, and attains a large size, often weighing six or seven hundredweight. The fresh-water tortoise is very abundant in North America, where there are fifteen species determined; the land tortoises, on the contrary, are chiefly African, although there are several European species.

The *Crocodiles* are divided into three groups—named respectively, *Alligators* or *Caymans*, true crocodiles, and *Garials* or *Gavials*. The first group are exclusively American, and have a wide range of distribution, extending from the United States, in lat. 32° 30″ north, through Central America, and southwards into Brazil and Paraguay, in lat. 31° south. They are amphibious, chiefly inhabiting the estuaries of great rivers, and rarely leaving the fresh water. They are very fierce, but chiefly prey in the night, and the South American species are considered less dangerous than those of the Mississippi. The African crocodiles extend from Congo to Senegambia on the west, and Egypt on the east, the common crocodile of the Nile being distributed over nearly the whole river district, and throughout Nubia and Abyssinia. The Asiatic crocodile, or Gavial, extends from the north-western coast of Australia, through the Indian Archipelago to Hindustan, where it is exceedingly abundant in the Ganges and other great rivers. The *Lizards* (including the monitors, iguanas, chameleons, blind-worms, and true lizards) range somewhat more widely than the former group, and many of them, as the chameleons and monitors, are absent in America. The Chameleons form an interesting African and Asiatic group, extending over many parts of the south of Europe. The Geckos and Iguanas are greatly multiplied in Brazil, but range also in other countries. The Monitors are chiefly Asiatic; and one, sometimes called the land crocodile, chiefly inhabits Africa and the Indian Archipelago. A nearly allied genus is found in Guiana, where it attains the length of six feet. The Skinks are distributed like the Iguanas, being chiefly abundant in Africa and South America; but there are ten species inhabiting Europe.

The *Serpents* are totally absent from the islands of the Pacific, and most widely distributed in the adjacent islands of the Indian Archipelago—a very remarkable fact in the general distribution of animals. It is also well worthy of careful attention, that although many species of the order are widely dispersed in various parts of temperate Asia and Europe, no species is common to Asia and America. Australia is almost without representatives, (there being only eleven species in all, and these peculiar,) and Japan has six species, also peculiar. America and Asia, between the tropics, present by far the largest number of species, and Africa is remarkably poor in species, although the few that there are seem very widely spread. Of the two divisions of serpents, the harmless and the venomous, the number of species of the former is three and a-half times as great as the latter, but with the exception of western Europe and Madagascar, scarcely any country is without some species of both.

The *Frogs* extend further than any other reptiles towards the polar regions, reaching in Finland nearly to the limit of perpetual ground-frost. In the New World, however, some of them extend even beyond this line in Greenland and British America, existing on the banks of the Mackenzie River, up to the sixty-seventh degree of north latitude, where the mean temperature is not more than seven or eight degrees Fahrenheit, and where the cold in winter is so excessive, that the thermometer sometimes sinks to more than 90° below the freezing point of water. In the southern hemisphere a frog was found by Mr. Darwin in latitude 50° south, on the banks of the river Santa Cruz.

Within the tropics Crocodiles and Boas are found on the Andes of Quito, at an elevation of 3000 feet; and a remarkable reptile, the *Axolotl*, occurs in Mexico at the height of 8000 feet. In the Alps there is a frog living in the vicinity of the snow-line, and various other reptiles of the same order between 4500 and 6000 feet. In the Pyrenees, the common frog is found at 8000 feet.

If we take the distribution of individuals we shall find by far the most abundant locality to be the Island of Java, after which Brazil, the southern States of North America, the Island of Sumatra, the Celebes, Egypt, South-western Europe, and North-eastern India may be mentioned as the places where reptiles chiefly abound.

153 *Distribution of the* MARINE VERTEBRATA.—This group includes the whale tribe, the seals, and a single genus of reptiles, in addition to the vast and important class of true fishes. The whales form two groups, the herbivorous whales (the *Lamantin* and *Dugong*) and the ordinary whales, including the *Dolphin*, the *Porpoise*, the *Narwahl*, the *Cachalot*, and the *Balæna*, or Whalebone whale. All these suckle their young. The lamantin, or sea-cow, is chiefly limited to the mouths of rivers in the hottest parts of the Atlantic Ocean, the American species being distinct from the African, but both occasionally attaining the length of fifteen feet and upwards. The dugong inhabits the Indian Ocean, and there is also an allied genus found in the Pacific. The spouting whales are very widely spread through the various parts of the great ocean, but there is no family of mammalia more difficult to observe, in spite of their frequently gigantic size. Amongst them the dolphin is seen in almost every latitude, and the porpoise is almost as widely spread, but particular species appear to be, and probably are, very much more limited. The Grampus is the largest species of this group, and abounds both in the Atlantic and Pacific Ocean. The Cachalot and Balæna are, however, much larger, attaining the length of from sixty to seventy feet, and the Rorqual (a whalebone whale) has been met with having a total length of as much as one hundred feet. The former appears to range from the limits of the Arctic nearly to the Antarctic Ocean, but their chief resort is in the deepest parts of the warmer seas near the tropics. The whalebone whales are chiefly found in the colder seas, but appear to travel to warmer latitudes in search of food.

The Seal tribe present a number of species of which the common seal and the morse are the best known; they are both chiefly confined to the polar seas and desert islands in high latitudes, but some of them have a very wide range, especially in the southern hemisphere.

The distribution of the true fishes, like that of the marine mammalia, is chiefly known as far only as regards the species used by man. Thus, the cod, the herring, the salmon, the pilchard, &c., have naturally attracted attention, and their habits of migration and the nature of the spots they select for feeding ground, are tolerably well known, but of the vast multitude that herd on the various shores of the different countries in the world, or that dwell concealed from observation in the deeper parts of the open ocean, it is scarcely possible to determine at present their true geographical or climatal limits, or the law of their distribution.

Of the various natural tribes of these animals, some are certainly migratory and some constantly confined to narrow limits, but the greater number have a wide, although by no means indefinite range. The former pass from one ichthyological province to another, according to the season and the abundance of food, or the necessities of breeding; but these provinces, although indicated, have been only partially determined. The most extensive includes about forty degrees of latitude on both sides of the equator, in the Pacific, and this is flanked by the northern and southern portions of the great ocean. The Atlantic presents a similar division, and there are many local and peculiar marine faunas in the great bays and gulfs near the mouths of great rivers, in the principal inland seas, and in the various rivers themselves.

Somewhat more than eight hundred and fifty species of fishes have been described from European seas, rivers, lakes, and coasts, of which two hundred and ten inhabit fresh water, and of the whole number two hundred and sixteen are British, and as many as four hundred and forty-four of the marine species are Mediterranean. Comparatively few of this number extend to America, still fewer are found in the Red Sea, and scarcely any reach to the Indian seas. It is remarkable, also, that the Black Sea, which communicates directly with the Mediterranean has a distinct fauna, and the Caspian another, also peculiar to itself. The great lakes of Central Asia and of North America, most of the great tropical rivers in both continents, and many other smaller areas of water, appear to be more or less isolated.

Although, in number of species, the southern seas of Europe and the warmer parts of the Atlantic are richer than the more northern districts, this is by no means the case with regard to individuals, or even the tribes most useful to man; and, indeed, in this matter, there seems a certain balance struck between the cold and warm regions; for while Italy and the south supply fruits and vegetables in enormous abundance, the northern shores and banks are eagerly watched for countless myriads of fish, which are dried and exported as food for the inhabitants of warm countries. Thus the banks of Newfoundland, and the Dogger Bank, in the North Sea, where there is shoal water and shelter, are crowded with cod in the month of February to such an extent, that in the latter locality as many as sixteen millions of fish have been caught in one place within a few weeks, and in the former, the produce of the fishery for a single season has amounted to forty thousand tons weight. The pilchard, in point of numbers, is still more remarkable, as it has been estimated that, on one occasion, twenty-five millions of fish (ten thousand hogsheads) have been taken on one shore in one port on a single day.

It is by no means the case, however, with these and many other fishes which migrate from one sea or part of a sea to another, that they can readily transport themselves to great distances. The contrary is rather the fact, as the pilchard and the herring are really limited to very narrow areas of sea, although appearing only at particular seasons, when impelled by instinct to the shores for the purpose of spawning; and so with others, where the migration is rather in vertical than horizontal space.

The limits of distribution of fish in vertical space seem to be very strictly defined. Some swim always near the surface, and, like the flying-fish, appear to rejoice in exposing themselves to the air, while others are still more nearly amphibious, and, like eels and an Indian species of perch, can transport themselves for some distance on land, or attach themselves to the shelter afforded by particular trees growing near water. Others, again, are littoral, inhabiting shores in moderate depth of water; but others, although found near shore, are, like the plaice and many flat fish, always buried in the mud or moving at the bottom. Many others, again, rarely or never approach the shores, but remain constantly in deep water; amongst these are the sharks. Mr. Yarrell has remarked, 'that those fish which swim near the surface of the water have a high standard of respiration, a low degree of muscular irritability, great necessity for oxygen, die soon—almost immediately when taken out of the water—and have flesh prone to rapid decomposition. Mackerel, salmon, trout, and herrings are examples. On the contrary, those fish that live near the bottom of the water have a low standard of respiration, a high degree of muscular irritability, and less necessity for oxygen; they sustain life long after they are taken out of the water, and their flesh remains good for several days. Carp, tench, eels, the different sorts of skate, and all flat fish may be quoted.'*

With tenacity of life is connected the extraordinary power observed in some fishes of enduring extremes of temperature, and thus the gold fish, a native of China, not only lives, but thrives to excess, in water whose temperature is constantly as high as eighty degrees Fahrenheit. Other species have been found in hot springs in various countries whose temperature ranges between 110° and 130° Fah., and Humboldt and Bonpland perceived

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* Yarrell's *British Fishes*, 1st edition, Introduction, p. xiii.

fishes thrown up alive from the bottom of a volcano, in South America, along with water and heated vapour, the thermometer showing a temperature within two degrees of the boiling point of water. The enduring power of fishes with regard to cold is, perhaps, still more remarkable, for Mr. Jesse speaks of a gold fish frozen with the water, in a marble basin, into one solid mass of ice, and yet, within a few hours of the ice having been thawed, the fish recovered, and was soon as lively as usual. The carp also, to which the gold fish is nearly allied, is well known to have remarkable power in this respect; and perch, as well as other fishes, are well able to sustain the congelation of the water surrounding them, without permanent injury.

154 *Distribution of the* INVERTEBRATA *and* ARTICULATA.—The *Invertebrate* animals are not less remarkable in their peculiarities of habit, and the limitation of their natural range, than the more highly organized groups already considered; and though some of them, as the *Sepias*, or cuttle fish, range freely in all parts of the ocean, or like the butterflies, flit about in the air and proceed like birds to distant countries, others are far more limited, and exhibit few capabilities of extensive or distant range. Thus, whether we consider the flying species, those which inhabit the surface or soil of the land, or the enormously larger and more important group, the marine invertebrata, we everywhere find natural limits of range, both in horizontal and vertical space, the increase of depth in the sea answering to greater elevation on land.

The *Articulata*, including insects, crustaceans (crabs and lobsters), and worms, are distributed in comparatively narrow and limited areas, so that a vast number of species have been determined, often differing very slightly from each other. In high latitudes, insects are very few, both in species and individuals, except during the short summer period, when certain tribes, as mosquitoes, fleas, and others, multiply with enormous rapidity, and prey upon all larger animals. In North Europe, and, indeed, in Europe generally, the number of species is much larger, and the variety far greater, and this increases as we advance towards the equator, but diminishes again in tropical Africa, while South Africa, the African and the Indian islands, are all richly supplied with these animals, although by no means to such an extent as Central America, which perhaps in some parts may be regarded as the true metropolis of the class. Beetles, however, generally, are much more abundant in temperate than in tropical climates, and this is especially the case in the northern hemisphere.

The causes that seem chiefly to affect the distribution and range of insects are—first, food; secondly, temperature; thirdly, prevailing winds; and fourthly, elevation above the sea. With regard to the first, as some insects feed upon living vegetables, these are necessarily limited to the range of such plants, and usually become introduced by man into those distant countries into which the plants are conveyed. More than two-thirds of the whole number of species are considered to be thus dependent directly on the vegetable kingdom. Temperature also acts indirectly by modifying the nature and amount of food, and in this way, as well as by immediate action on the animals themselves, produces a considerable change. It is, however, pretty certain that extremes of temperature have chiefly to be regarded in considering the direct action of climate, as where there is considerable summer heat many of these creatures will easily withstand the action of the greatest reduction of temperature, even in the polar regions. The common mosquito, the flea, and the common fly, are examples of this.

Mountain chains form natural barriers to the passage of most kinds of insects. As an example of the extent to which insects are sometimes multiplied, and, therefore, of the way in which they may be said to affect the aspect of any fauna, we need only refer to the following account of the condition of some of the great rivers of tropical America, and the swamps near their mouth. According to Humboldt, 'there is no rest in these spots at any hour of the day or night, or at any season of the year, so that whole districts are absolutely left desert from the impossibility of enduring life under such torture. New species follow one another with such precision, that the time of day or night may be known accurately from their humming noise, and from the different sensations of pain which the different poisons produce. The only respite is the interval of a few minutes between the departure of one gang and the arrival of their successors, for the species do not mix. On some parts of the Orinoco, the air is one dense cloud of poisonous insects to the height of twenty feet. It is singular that they do not infest rivers that have black water, and each white stream is peopled with its own kinds; though ravenous for blood, they can live without it, as they are found where no animals exist.'

In Brazil, the quantity of insects is so great in the woods, that their noise may be heard in a ship at anchor some distance from the shore. The torrid zone not only produces the most noisy, but the most brilliant and the most powerful insects. Amongst the former are the butterflies of Africa, the East Indies, China, and America, which rival the lustre of metals in their colours; and here also the forests, peopled with millions of fire-flies of various kinds, present to the eye an appearance almost like that of an immense conflagration. The Termes, or white ants of Africa, build solid hillocks, and in the course of an incredibly short time can remove every particle of flesh even from the carcass of an elephant; they are so destructive in South America, that there is said to be not a manuscript in that country a century old. Spiders also, although there are more species in Europe than elsewhere, attain a gigantic size only in hot countries, where, as in Guiana, a species is found large enough to catch and devour birds.

The migration of insects, like that of birds, is necessarily obscure to a certain extent, but tribes of Locusts are known occasionally to transport themselves from one country to another, in a mass so dense and so large as to form a visible cloud in the air, darkening the sun's light, and making with the beating of their wings a sound which is said to resemble the distant murmur of the sea.* The main body when thus compacted, sometimes proceed to great distances, crossing the Mozambique Channel from Africa to Madagascar (a distance of 120 miles), and proceeding occasionally from Barbary into Italy. Many other insects are remarkable also for the great distances of their flight, and the vast multitudes collected together for this purpose.

The *Crustaceans,* which are also Articulata, include a number of marine species, chiefly littoral, besides many from the fresh water, and some that are terrestrial. In the Polar seas they are found in great abundance, though the number of species is very limited; and in the equatorial regions, while they are no less numerous, they present a greater diversity of form, attain a larger size, and exhibit in the highest perfection those peculiarities of structure by which the several groups are characterised. The Land-crabs are chiefly remarkable in the table-lands (Ghâts) of the peninsula of India, and in the West Indies. In the former country they are troublesome, and indeed dangerous,. by their extensive burrowings, but in the Antilles are eaten as food.

The *Annelids,* like the Crustaceans, include inhabitants of the land, of fresh water, and of both shallow and deep ocean. Some also, as the Earthworms, live permanently beneath the surface of the Earth. They occur in all climates, but are not able generally to wander far from the specific centre to which they belong. The marine species are chiefly littoral.

155 *Distribution of the* MOLLUSCA *and* RADIATA.—The Mollusca are regarded as, on the whole, of lower organization than the Articulata, although they include amongst them one group (*Cephalopoda*) which approaches the

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* 'A fire devoureth before them; and behind them a flame burneth: the land is as the garden of Eden before them, and behind them a desolate wilderness; yea, and nothing shall escape them. . . . Like the noise of chariots on the tops of mountains shall they leap, like the noise of a flame of fire that devoureth the stubble, as a strong people set in battle array.'—*Joel,* ii. 3—5

Vertebrata very closely. They are chiefly marine, although there are many fresh-water and terrestrial species. The aquatic species are found in all seas from the poles to the equator, but generally at moderate depth, some burying themselves in sand or mud, others in indurated clay, and some burrowing into limestone rocks. Many species delight in quiet sunny nooks on the margin of fresh-water pools, others in rapid and mighty rivers, and others, again, in the depths of the ocean, but all are exceedingly dependent on local condition. We cannot better give an idea of the nature of the distribution of these and other lower animals, than by quoting the following summary from the admirable memoir by Professor Edward Forbes on the Ægean Invertebrata.* Professor E. Forbes divides the portion of sea to which his observations were chiefly confined into eight regions of depth, each characterised by its peculiar fauna; 'certain species in each are found in no other, several are found in one region which do not range into the next above, whilst they extend to that below, or *vice versâ*. Certain species have their maximum of development in each zone, being most prolific in individuals in that zone in which is their maximum, and of which they may be regarded as especially characteristic. Mingled with the true natives of every zone are stragglers, owing their presence to the action of the secondary influences which modify distribution. Every zone has also a more or less general mineral character, the sea bottom not being equally variable in each, and becoming more and more uniform as we descend. The deeper zones are greatest in extent, the first or littoral zone extending only to two fathoms, the second from two to ten, the third from ten to twenty, the fourth from twenty to thirty-five, the fifth thence to fifty-five, the sixth to seventy-nine, the seventh to one hundred and five, and the eighth to two hundred and thirty fathoms; below this, at a depth of about three hundred fathoms, there are supposed to be no living animals.' It must not be imagined that exactly similar regions are to be met with in every sea, that there are always the same number, or that the limits of animal life are invariably the same as in the Ægean Sea. We take this as the best example that has been hitherto worked out, and there is no doubt of there being some determinable order of distribution in most other seas, whether confined or open.

The indications as to climate or distribution which may be drawn from the examination of the Testacea will be found to vary, not only according to depth, but also from the nature of the ground. A comparison of the various animals of the lowest zones with those of the higher, exhibits also a great distinction in the hues of the species; those from great depths being generally white or colourless, while those from the higher regions exhibit more usually brilliant combinations of colour. The chief cause of this is no doubt the increased amount of light above a certain depth, but the nature of the feeding-ground and the food must also exert a modifying influence.

Every species has two *maxima* of development in space, one in depth, and another in horizontal area; and in each we find a species at first represented by a few individuals, which become more and more numerous till they reach a certain point, after which they gradually diminish, and at length altogether disappear. Sometimes the genus to which the species belongs, ceases with its disappearance, but not unfrequently a succession of similar species is kept up, representative, as it were, of each other. When there is such a representation, the minimum of one species usually commences before that of which it is the representative has attained its corresponding minimum. Forms of representative species are similar, and often only to be distinguished by critical examination. When a genus includes several groups of forms or sub-genera, we may have a double or triple series of representations, in which case they are generally parallel.

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* *Reports of the British Association for the Advancement of Science*, Cork, 1843, pp. 154 & 173.

'The consideration of the representation in space forms an important element in our comparisons between the faunas of distinct seas in the same or representative parallels. The analogies between species in the northern and southern, the eastern and western hemispheres, are instances. But there is another application of it, which I would make here. The preceding tables and list afford indications of a very interesting law of marine distribution, probable *à priori*, but hitherto unproved. The assemblage of cosmopolitan species at the water's-edge, the abundance of peculiar climatal forms in the highest zone where Celtic species are scarce, the increase in the number of the latter as we descend, and when they again diminish, the representation of northern forms in the lower regions, and the abundance of remains of Pteropoda in the lowest, with the general aspect of the associations of species in all, are facts which fairly lead to an inference, *that parallels in latitude are equivalent to regions in depth*, correspondent to that law in terrestrial distribution which holds *that parallels in latitude are representative of regions of elevation.* In each case the analogy is maintained, not by identical species only, but mainly by representative forms; and, accordingly, although we find fewer northern species in the faunas of the lower zones, the number of forms representative of northern species is so great as to give them a much more boreal or sub-boreal character than is presented by those regions where identical forms are more abundant.'*

The laws of distribution of Mollusca and Radiata are not yet so distinctly made out as those affecting the Vertebrata generally, but they appear, from what has been said above, to be of very similar nature. Certain seas present innumerable multitudes of some species, which do not extend beyond certain well-marked, if not narrow limits; other seas are equally remarkable for a mixture of groups, and an absence of definite character. These points at first seem to present difficulties almost insuperable to the proper working out of the various laws, for the exceptions are both numerous and unexpected. It is only when we include the element of *time*, and consider the laws of succession as well as distribution, that we find the explanation of such apparent anomalies; and that the apparent disorder and confusion result in order, and a more distinct apprehension of the unity of plan and system throughout nature. We now proceed to examine briefly the evidence of such succession and representation in time, and thus connect the present history of the Earth with that past history, which, in the case of organized beings, is now recognised as a distinct science under the name of Palæontology.

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* Professor E. Forbes, *ante cit.*

CHAPTER XII.

DISTRIBUTION OF ORGANIC BEINGS IN TIME.

§ 156. Nature of organic remains, and proof of the existence in the Earth's crust of fragments of Plants and Animals belonging to Species now extinct. — 157. Distribution of extinct Mammalia in time. — 158. Distribution of extinct Birds. — 159. Distribution of extinct Reptiles. — 160. Distribution of extinct Fishes. — 161. Distribution of extinct Mollusca. — 162. Distribution of extinct Articulata. — 163. Distribution of extinct Radiata. — 164. Distribution of extinct Plants.

NATURE of Organic Remains, and Proof of the Existence in the Earth's Crust of fragments of Plants and Animals belonging to Species now extinct.—Most of the numerous deposits met with in different parts of the Earth are, as we have already intimated, loaded with the remains of plants and animals of various kinds, but chiefly those of the sea, accumulated contemporaneously with the inorganic materials of the beds themselves, and therefore in most cases strictly indications of the actual condition of the sea bottom within a given area, and during a limited period. These remains, therefore, afford materials for a history of the past condition of life on the globe, and they afford indeed the most distinct information concerning this history. They are called *fossils;* and the use of this word is now limited to such organic remains, as being of all things that are dug out of the Earth those of greatest interest to man in his efforts to penetrate into the past.

The fossils that have been found appear to be distinct in all the essential characteristics of species from the recent animals and vegetables of the same district; and this is the case, whether we regard the living representatives, or those lately embedded in superficial deposits, or whether we look into those deeper and more metamorphosed beds, which from their position beneath a vast mass of fossiliferous strata, are manifestly of great age when compared with the existing creation.

Every particular group of deposits in all parts of the world is more or less distinctly characterised, not only by its peculiar mineral character, but also, and far more distinctly, by the groups of species which together make up its fossil fauna and flora. These usually differ much less in any two adjacent conformable beds than in others which are separated by intermediate bands, whether such intervening masses contain organic remains or are destitute of them; and they are also more alike then than when the beds are not parallel to, or have immediately succeeded each other, but have been disturbed between the completion of the lower and the commencement of the upper series.

Generally it may be regarded as a law deduced from observation, that the species of animals characterising any one geological period have either originated during this epoch, or have then attained their maximum development in number. It also appears that species were on the whole more widely distributed at the time when the older rocks were being deposited than they are now; that the departure from a given type or form is greater the farther back, or older, the formations that we refer to; and lastly, that the remains of animals found in the older rocks exhibit by degrees, as we retrograde in order of time, a larger preponderance in number of invertebrated over that of vertebrated species, till at length we reach formations in which no remains are found higher in organization than the mollusca.

The first of these laws—that which involves the statement that '*fossils are characteristic of formations,*' is one which is of great importance, as it involves two very distinct and startling assumptions—that the fossil remains found are those of animals and plants, of which not only the individual but the species is now dead, or extinct from the Earth, and that there has been not one only, but a long succession of creations of species to supply the place of those that have from time to time thus become lost. The former assumption has been so fully proved in every work on Geology and Palæontology; is so clearly illustrated by the absence now of species once common, and their replacement by others; and agrees so well with the probabilities of the case, that we must here take it for granted. The occasional loss of species, genera, and even families, from their place in creation is now recognised by every naturalist, and we only refer to the subject to complete the line of argument. The successive creation of groups of species to repeople the Earth when old ones have departed seems, however, far more questionable, and it is more reasonable and more consistent with the facts that are known on the subject, that we should assume the introduction to have been very gradual, species after species, as occasion seemed to require. As in the different countenances of various individuals of our own race, there is a distinct expression in each individual, which identifies him, although all are of one species and possess innumerable points in common, so in the representative species of some important genus, we see the same kind of resemblance and difference; and so also in the group of species of a certain epoch, we may recognise a physiognomical character, which yet admits of these species being replaced in other groups by individuals resembling them, but not at all to be mistaken. The true meaning of the law seems, therefore, to be, that taking each formation as including a group of deposits, formed under similar or very slowly changing circumstances for a certain duration of time, and represented in different parts of the world at that time by other species having similar resemblances and differences to those which are found to affect a fauna or flora now in different geographical areas, we may perceive by careful study that amount of unity of character which will enable us to recognise the group of species and distinguish it from that found in other beds that are contemporaneous, even when there exists no other evidence of their contemporaneity. The actual limitation of a group of species to a particular group of beds has not, we believe, been at all satisfactorily proved with regard to any one case.

The second law, 'that species belonging to more ancient periods had a wider geographical distribution than those now living,'* is also to be understood as true only in a general sense, and with many limitations and apparent exceptions. We shall, indeed, find in particular cases, that species of manifest importance are spread much more widely in older rocks than their representatives are now, or have been since; and as this is the case with large groups of those species which must themselves be regarded as highly characteristic, in particular instances the law may so far be regarded as established. It has been mentioned as a deduction from the operations of this law observed in various ways, that the temperature of the Earth's surface has undergone change, and this, indeed, may have well happened from those numerous alterations that we know to have taken place with regard to the relative level of land and water, and the absolute quantity of land above the water. We believe the weight of evidence in this question does not preponderate in favour of the views of those who believe the Earth to have cooled down from an incandescent state since organic beings were introduced on its surface.

The third law enunciated is, that the more ancient the formation, the more widely do its fossil contents depart from the existing type; and this is really the simple expression of facts, made out by numerous long continued and careful observations in various parts of the world, and may, therefore, be fully relied on.

The fourth and last of these laws asserts, that the faunas of the most

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* See Pictet's *Paléontologie*, vol. i. p. 73.

ancient formations are, *cæteris paribus*, numerically richer in animals of low organization, and chiefly in Mollusca, than those of more recent deposits; but this—although in one sense the mere statement of a fact which cannot now be questioned, since all observations up to the present time have tended to confirm it—is yet not to be received without some qualification. It may be said, indeed, as an answer to any theory of development, or of the existence of a scale of beings gradually approaching perfection, that although it is true in the ancient epoch, that only the remains of fishes are found amongst invertebrata, and that even these at length disappear, yet the faunas even of the earliest periods are by no means imperfect, and we ought not to be hasty in assuming the absence of the more perfect types in the older rocks, merely because we have not yet discovered any remains of them. This is well exemplified in the case of many parts of the world at present; for putting aside the presence of man, we find the fauna of Asia apparently superior to that of Europe, if we regard merely the extreme point of organization, since in the former continent we have the Orang-otang, and in the latter scarcely a single ape, and few carnivores of large size. According to this rule, indeed, the fauna of New Holland would indicate a condition of the Earth greatly less developed than that of any other country, since the only mammals are didelphine; but it is clear, that a very false notion of the general condition of the Earth's surface at the present time would be obtained by the most careful consideration of the organic remains found in the islands of the Indian Archipelago, and the Pacific Ocean.

In point of fact, neither the Radiata, the Articulata, the Crustacea, the Mollusca, nor fishes, were at all imperfectly represented or developed in ancient times, and ever since their first appearance, the members of these classes of animals have possessed the same degree of perfection as their modern representatives. It is a mistake to suppose that the early faunas, generally, were composed of animals less perfect than the recent ones, although no doubt the highest point to which organization has reached, has risen during successive geological periods, so that while cephalopods, or fishes, first formed the superior limit of organization, these were afterwards surpassed by reptiles, and these also, after an interval, by mammals.

Two courses are open to us in this attempt to communicate a true notion of the distribution of animals in time. We might either take the various periods, or the natural groups of species, as the means of representing the absolute facts determined. Although, however, a correct idea would be best obtained by a combination of the two methods, we propose here to give only an outline of the various tribes of animals as they are represented in the faunas of different periods, leaving the other division of the subject to be studied in works devoted expressly to Palæontology.*

157 *Distribution of extinct* MAMMALIA *in time.*—Organic bodies generally are only preserved in strata, so far as they present hard and comparatively indestructible portions in their skeletons, and since most of the mammals, birds and reptiles, are land animals, while the greater number of deposits are of marine origin, the distribution of these is also limited to such deposits as have originated either near land or near the mouths of great rivers. Amongst Quadrupeds, the teeth offer at once the hardest and the most distinctive characters, and these can rarely be mistaken, and are seldom injured materially by long exposure to decay.

Amongst all the mammalian and bird remains that have occurred, but few belong to those rocks which are called secondary, and none at all to the Palæozoic group. With a very remarkable exception, occurring in the Stonesfield Slate (one of the beds of the lower Oolites of England), no true quadrupedal remains so old as the chalk have yet been obtained.

The remains of mammals are, therefore, almost confined to the rocks of

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* See *The Ancient World*, by the author of this treatise, where an attempt has been made to give a popular and connected view of the Earth's organic history.

the tertiary period, but are there very abundant. They include species of all the natural orders, with the exception of man, and no fossils that have been found require the formation of new orders.

Of *Quadrumana*, the number of remains that have been found is small, but they offer matter of great interest for the comparative anatomist. Several species have been determined from India (lat. 30° N.) from the tertiary rocks of the Sewâlik hills, one of them of gigantic size, and at least as large as an Orang-otang. In Europe, also, the order is represented, one species having been found in France (at Sansans, in 43° N. lat.), which is described as intermediate between the gibbons and solemn apes; and two species in England, in the older tertiary beds of the London Clay, which appear to belong to the group of Macacques (*macacus*). Remains of Monkeys, of gigantic size compared with the existing species of that continent, have been found also in Brazil.

The remains of Bats (*Chiroptera*), have been found scarcely more abundant than monkeys, and they are confined hitherto to the insectivorous group. Of these one species is mentioned by Professor Owen, from the older tertiary sands of Kyson (Suffolk), where the monkeys' remains occurred, and another is known (also older tertiary) from the Paris Basin. A single species is described from Œningen, in newer tertiary schists, and fragments of several species, some of them not extinct, have been found in caverns in England, Belgium, and elsewhere. A few species have been determined from the cavern remains of Brazil.

The *Insectivora* present some extinct and some recent species in a fossil state, but considering the almost universal distribution of some tribes at present, and the aquatic habits of many of the species, it is perhaps remarkable that the extinct forms should be so very few, and so exceedingly rare as we find them to be. One species of Hedgehog, one of Shrew, and one of *Mygale*, have been found at Sansans, and an extinct genus nearly allied to the mole, but as large as the hedgehog, was associated with the gravel animals whose remains are found at Bacton, on the Norfolk coast of England.

One of the most interesting of all the mammalian fossils found in the Oolitic beds of Stonesfield, and already alluded to as affording evidence of the great antiquity of mammals on the Earth, has been referred by Professor Owen to this order of Insectivora, under the name of *Amphitherium*. For the evidence on this subject we must refer to Professor Owen's beautiful work on the *British Fossil Mammals*, p. 29.

There are many more species of Carnivora found fossil than of those orders yet referred to, Of the *Plantigrade* group, a considerable number of species, and, indeed, several new genera, have been described from remains found in caverns and other superficial deposits. Of the most remarkable and interesting is the great Cavern bear (*U. Spelæus*), whose bones abound in many large caverns in Germany, and are met with also in England. Other species are known from Central France, Algiers, Brazil, and the Sewâlik hills, all, however, of the tertiary, and many of the gravel period. Species of Badger, Weasel, Glutton, and Coati, have also been found fossil.

The Digitigrade Carnivora are represented by fossils from most of the tertiary deposits. In the Paris Basin and other older tertiaries, we have the Dog (*Canis*) represented by two or three extinct species, while the Genette and the Otter exhibit one, and the cat-tribe (*Felis*) several.

The middle tertiaries, however (chiefly in France and the Rhine Valley), contain more both of species and individual remains than the older, and the newer many more than both together, far the most remarkable and most interesting of the group belonging, in fact, to the gravel, except those which have been met with in India, and of these the age is somewhat doubtful.

Of gravel fossils obtained from England, and belonging to this group, we may enumerate the *Felis spelæa*, or cavern tiger; the *Machairodus*, a gigantic carnivore of the most ferocious habits and of great strength; a Wild cat, the Cavern hyæna, the Wolf, Fox, and some others of existing or closely allied species. Besides the cavern hyæna, other species occur in deposits of the same age in India and Brazil, and this is the case also with the genus *Felis*, of which no less than six species have been described by Lund from the Brazilian caverns, varying in size from that of the jaguar to dimensions something less considerable than those of the domestic cat, and presenting some curious anomalies. The *Amphibia* are only at present known in a fossil state by two or three species of Seal, one found at Angers, one in the tertiary marls of Osnaburgh, and others on the shores of the Mediterranean. Fragments of a fossil Morse (*Trichechus*) have also been described, and various bones of Whales, both in this country and North America.

The tribe of *Rodents*, although represented in a fossil state by many species, has not been very much studied. They have been found in the gypsum beds of Montmartre, in the middle tertiary beds of Auvergne, or in the diluvial deposits of caverns and osseous breccia. Asia and America, as well as Europe, have yielded such remains, and many of those in more recent beds are with difficulty distinguished from existing species. Of the various tribes of these animals we find Squirrels and a species of *Myoxus* in the older tertiaries, and an *Arvicola*, a *Hamster*, and others, in Auvergne and at Epplesheim. The Beaver, and an extinct and nearly allied, but gigantic species (? genus) (*Trogontherium*) are found in the newer tertiary, and many others occur in the gravel, among which, in Europe, may be reckoned representatives of most of the chief existing European genera, and in America a multitude of new species closely allied to the forms at present existing in that continent.

The *Ruminants*, infinitely important to man, and now extremely abundant in individuals, varieties, species, and genera, did not present the same preponderance during the later tertiary periods, and were, it would seem, exceedingly rare during the earlier part of this last portion of our Earth's history. Many species, very nearly allied to the group and distinctly representative of it, are referred to the order of *Pachydermata*, and those that remain are confined to the gravel or newest part of the period, except, indeed, that the deposits of India prove their existence in that country at a much earlier period. The Indian species include two Camels, and a third occurs in Siberia. One or two species of *Moschus* (musk-deer), species of *Antilope*, *Cervus*, *Bos*, *Bubalus*, and others, are found in the same locality. In addition to these, there has been found another and very remarkable genus (*Sivatherium*), now quite extinct, in which the head is not only provided with horns, like other true ruminants, but no less than two pair appear (including both those now characteristic of principal natural groups of the order), and with these are associated peculiarities of the skeleton, apparently indicating a very close approach to the pachyderms, and especially the elephant.

The ruminants of the diluvial period in England, and of the caverns of Brazil, and other parts of the world, include numerous species, very nearly allied to those now indigenous in the same districts, but others as remarkably distinct. Thus, the gigantic Irish elk and several species of Cervus (deer) afford admirable examples of the former, and the existence of remains of a Giraffe in Central France not less striking evidence of the latter condition.

The distribution of the *Pachydermata* during the tertiary period is especially interesting, as it is chiefly from this order that the most striking and characteristic, and even representative forms, seem to have been obtained during the earliest part of the tertiary period. The extinct species are also interesting, since, in many cases, they fill up gaps now existing in the order, and connect this with the not very similar groups of Ruminantia, Rodentia, Carnivora, Cetacea, and Marsupialia. The lacunæ thus filled up show how complete the scheme of nature is, and they show also, that during one part, at least, of the Earth's history, and over an extensive portion of the surface, one group of quadrupeds preponderated, and included animals having all varieties of habit, just as, at the present time, the marsupial tribe is developed in Australia, almost to the exclusion of other races.

The most ancient forms of Pachyderms are those described by Cuvier under the name *Palæotherium, Anoplotherium, Anthracotherium, Hyracotherium, Lophiodon*, &c. These gave place to *Dinotherium, Rhinoceros*, &c.; and these again to *Mastodon, Elephant*, other species of *Rhinoceros, Hippopotamus*, &c., in the Old World, accompanied (not replaced) by *Macrauchenia, Toxodon*, and others, in South America. In India, there were besides these a number of very curious species, forming an exceedingly rich fauna, to which the order Pachydermata furnished the greatest number of species, and appears most to affect the physiognomy. We need not here describe the peculiarities of these singular animals, as they will more properly come under consideration in the next chapter. In England, of about twenty mammals distinctly made out from the older tertiary beds, more than twelve are Pachyderms; but from the deposits of more modern date, although the number of mammals is very much more considerable, there are but seven from the gravel beds, seven from caverns, and three from the alluvium, and this relative preponderance in the older rocks of the period seems universally observable, although it is most strikingly the case in the beds found near Paris and those of the London Basin. It is worthy of remark, that the physiognomy of the fauna is very greatly affected by this order in the older tertiaries, not only because there are so many representative forms of the other, and more recently developed natural orders of quadrupeds, but because the multitude of individuals as well as species, and the largest and most important of the quadrupeds, were of this kind.

The *Edentata* are now almost confined to South America, only a few representative forms extending to Asia and Africa. Their distribution in ancient times was apparently not very different so far as geographical area is concerned, as the fossil remains have hitherto been found only in the present metropolis of the order. The extinct species are, however, extremely different in form and magnitude from the existing ones, presenting some of the most extravagant departures from existing types yet met with, so that though the number of species is not large, their investigation becomes a subject of great interest. The remains of the gigantic representations of the Sloth and Armadillo range, however, more widely than the species now characteristic, at least one genus (*Megalonyx*) having reached as far north as Virginia, U.S., while others extended far down into Patagonia. There are two principal groups, one represented by the *Megatherium, Mylodon, Megalonyx, Scelidotherium, Cœlodon*, and *Sphenodon*, the corresponding existing genus being the Sloth. The other group contains *Glyptodon, Hoplophorus, Pachytherium, Chlamydotherium*, and two others, which all, more or less, resembled the Armadillo. One or two fragments of bones from the Plata have been doubtfully assigned to animals of which the Ant-eater is the modern type. Most of the genera above-named are confined to a single species, and they are all of the very recent tertiary period.

As the Edentata are chiefly found fossil in America, where the existing forms appear, so the order *Marsupiata*, at present characteristic of Australia, is that to which the greatest number of mammalian remains of the same country must be referred, and few occur elsewhere. There is, however, one remarkable exception in the Stonesfield Slate, where a Didelphine species has been discovered accompanying the Insectivorous mammal before described. With this exception, and a couple of species in the older Tertiaries of London and Paris, all the extinct forms are Australian, and include Kangaroos, some of them of gigantic dimensions, and a Wombat. They occur in caverns, chiefly in Wellington Valley, about 200 miles north-west of Sydney, New South Wales.

158 *Distribution of extinct* BIRDS.—The remains of birds occur but rarely, and are usually very imperfect. Footmarks, however, have been found which it is difficult not to refer to animals of this kind, in rocks of very ancient date, and thus the class of birds may be referred back much further in date than the mammals. Impressions of birds' feet occur in the red sandstone of

Connecticut, United States, and in beds of similar mineral composition, and belonging to the oldest portion of the secondary series in England and Germany. The former have been generally described as carboniferous; the latter are certainly from the newer red sandstone, above the magnesian limestone. The evidence on which the correctness of their reference to birds may be considered to rest, arises from the shape, which requires that the animal that made them should have been a biped—that the feet should have been tridactyl or three-toed, the middle toe much the longest, and each terminated with claws, and that sometimes there was a fourth short toe behind. It cannot be regarded as impossible that reptiles may have been so constructed as to leave impressions of this kind, and as few remains of birds' bones have been found in other rocks of the secondary period,* but little evidence concerning these animals is obtained till we examine the older tertiary beds of the Paris Basin. There, however, and in the London Basin, and again in numerous other tertiary rocks where circumstances were favourable for their preservation, such indications are found as leave no doubt that Birds accompanied the Pachyderms, Carnivores, and other representatives of the class Mammalia, in tolerable abundance. The older tertiary species include a Vulture from the London Clay, a species referred doubtfully to the King-fisher tribe (*Halcyonidæ*), and a small wading bird from beds of the same age, besides several related more or less closely to the Pelican, Sea-lark, Curlew, Woodcock, Owl, Buzzard, and Quail, from the Paris Basin. The newer tertiary beds have also supplied several species; and in the gravel, or in caverns, there have been found remains of species of Raven, Lark, Pigeon, Duck, and Snipe.

In South America, and especially in Brazil, where caverns have been so effectually searched for fossil remains by M. Lund, there have been found fragments of several birds, amongst which may be mentioned two Ostriches much larger than existing American species; while in New Zealand other remains have been found in great abundance, distinctly referable to an extinct and gigantic race of wingless birds—the prototypes of the small Apteryx, at present characteristic of the same island. Many species of these have been described, and various genera named to include them.

159 *Distribution of extinct* REPTILES.—The distribution of reptiles in time is a matter of great importance to the Geologist, inasmuch as these animals seem really to have been the chief inhabitants of the Earth during the middle period of its existence, and their remains are not only more abundant, but more perfect, and also more distinct from the existing representative species—at least so far as the continent of Europe is concerned—than any of those hitherto considered. It is here first that new orders require to be defined, to include species far removed in habit and structure from known forms, and some of these are so strange that description can hardly exaggerate the singular departure from all we are in the habit of considering.

If the reader refer to the list of orders of *Reptilia* in a previous page, he will find three mentioned as not existing now in a recent state, and known only by organic remains, found in rocks chiefly of ancient date. In addition to these three, however, all the existing orders have some fossil representatives, and some of them a considerable number, contained in genera which can no longer be recognised as including recent forms. We proceed to consider briefly the distribution of the different species of fossil reptiles in time.

The most ancient reptilian remains are those which accompany the supposed birds' footprints in the Carboniferous (?) sandstone of Connecticut. We find also various footprints in these rocks which have been referred

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* One specimen was found by M. Von Meyer in the cretaceous slates of Glaris, having the form and general characters of passerine birds. Another specimen, from the Wealden beds of Kent, is referred very doubtfully to albatross, and a large wading bird has been determined from Tilgate Forest, (also Wealden.)

chiefly to Chelonia (turtles and tortoises), and similar markings have sometimes been described as fossil footsteps in the sandstones of ancient date in our own island.

The most ancient actual bones of reptiles hitherto discovered occur in the magnesian limestone beds of the neighbourhood of Bristol, but it may be permitted to doubt whether these are not rather of the secondary than the Palæozoic period. In the middle beds of New Red Sandstone in Cheshire and Warwickshire, many very interesting fragments of bones have been met with besides footprints, all tending to prove that at that period many reptiles existed, varied in form and dimensions, and belonging probably either to the Batrachian or the Lacertian order. Beds near the Cape of Good Hope (South Africa) have yielded also fossils which partly from independent geological evidence, but chiefly from the character of these remains themselves, are regarded as older secondary. Numerous footprints in the New Red Sandstone seem beyond a doubt reptilian.

The rocks of the secondary period form a perfect necropolis of the reptilian tribe, and in the Lias, which succeeds the New Red Sandstone, we find a multitude of remains of the *Ichthyosaurus* and *Plesiosaurus*, the chief representatives of the order *Enaliosauria*. These remarkable animals, which were apparently strictly marine in their habits, and even more thoroughly adapted for aquatic existence than the cetacean mammals, were singularly abundant in the argillaceous bed already alluded to, but continued, not only by the preservation of the genus, but in some cases by identical species, through the whole oolitic series into the chalk, receiving an additional genus during the deposit of the newer oolitic rocks. In the lower Oolites (Stonesfield Slate, already more than once referred to for its fossils) the order *Dinosauria* also appears, and is represented by the carnivorous and gigantic *Megalosaurus*, which appears to have continued where circumstances admitted, and in the newest part of the Oolitic period (Wealden) was accompanied by the *Iguanodon* (a herbivorous genus, also gigantic), and the *Hylæosaurus*. Not only, however, were these two remarkable orders of marine and land saurians first presented during the middle part of the secondary period, but they were accompanied by the *Pterosauria* or Flying saurians, a race yet more unlike existing forms and the inhabitants of the air. The only genus yet described by these animals (*Pterodactyl*) appears first in the Lias, but was continued like the marine tribe into the Chalk, and presents, like the others, a considerable number of species. It is chiefly in England and Western Europe that these remains have been found, since there the oolites are chiefly developed, and seem to have been accumulated under the most favourable conditions.

The order of *Crocodilia*, or mailed saurians, was richly represented in the secondary period. Of the three divisions (those of which the vertebra are bi-concave, convexo-concave, and concavo-convex, respectively), the first contains the *Teleosaurus*, a kind of gavial, extending from the Lias into the Middle Oolites, and another genus, also oolitic, besides two generic forms (*Suchosaurus* and *Goniopholis*), both Wealden. The second (convexo-concave) contains several species, the older ones occurring in the Lower Oolites, and the newest in the Wealden; while the third (concavo-convex) includes all the existing crocodiles: one doubtful cretaceous species, several of the tertiary period, from the London and Paris Basins, and some of the middle tertiary deposits of Central France.

We have already referred to the *Lacertians*, as containing the most ancient representative forms of the great Reptilian class. Besides those already mentioned, there is another New Red Sandstone species, referred to a distinct genus (*Cladyodon*), whilst the *Geosaurus* is found in the Solenhofen (Upper Oolitic) beds, besides two or three genera met with in the chalk, of which that called *Mosasaurus* is the best known. The *Leiodon* is nearly allied.

The *Chelonians*, recognised by numerous foot-prints in the older rocks and New Red Sandstones, are distinctly exhibited, by fragments, in a fossil state, in the oolitic beds, but they are almost confined to the Stonesfield slate in England, though on the continent of Europe some of the other oolitic rocks have yielded similar indications. In the Wealden rocks more numerous and characteristic fossils of this kind appear, and, like the others, they belong to the emydian tribe, inhabiting marshy and swampy places. The true fresh-water turtles are found in the triassic rocks and lias, and in several tertiary deposits. True marine turtles (Chelonians) have been found in the Portland and Purbeck rocks, and in various tertiary strata, especially of the older part of the period.

The fossil remains of Serpents (OPHIDIA) have not been found in rocks older than the London Clay, and only a few species have been described from that locality. These animals appear to have had gigantic representatives during the older tertiary period in Great Britain, but since then have disappeared from these parts of the world, or at least have left only a few species of comparatively small size. The BATRACHIANS, also, once presenting very remarkable forms, approximating them to the Crocodilians, have not of late exhibited any aberrant forms. Fragments of frogs and salamanders are found, occasionally, in tertiary rocks, but few striking deviations have been seen amongst the more recently deposited fossils from the most ordinary existing types.

160 *Distribution of extinct* FISHES.—Most of the deposits containing fossils having been formed under water, it is not astonishing that a very large proportion of the organic remains preserved should have belonged to marine animals; and thus it follows, that although rarely so characteristic, or in themselves so valuable for determination, the remains of marine animals afford, from their number and preponderance, the principal means of becoming acquainted with the ancient conditions of life on the globe. Fishes, as the most highly organized of marine animals (except, indeed, Cetaceans, whose remains are rare and comparatively unimportant) thus assume an importance in Palæontology, which they do not possess in general Zoology.

We have spoken above of the division of fishes into four orders, according to the structure of their scales. Of these four orders, two are absolutely confined to the rocks of the Cretaceous and Tertiary periods and existing seas. The other two are also still represented, but by comparatively few species, and these, with the exception of the Squaloid, or Shark family, not the most important ones. It thus happens that the termination of the Oolitic (including the Wealden) period, exhibits the most perfect break in the whole series, so far as this class of animals gives evidence, and two families of fishes (the Sturgeons and Rays) also take their rise at the commencement of the secondary period, while the Hybodonts disappear at its termination. It is worthy of note, that not only are the fishes of the Palæozoic period limited to two of four of the natural orders, but they are confined to one group of these, characterised by the continuation of the vertebral column into the upper lobe of the caudal fin, producing a much more considerable development of that part, and thence called *Heterocercal.* These, which were abundant during the Palæozoic or Older fossiliferous period, then became very rare; the rocks of the secondary series chiefly present *homocercal* fishes, or those which have the caudal fin equally developed, and proceeding entirely from the extremity of the vertebral column, or at least have very few that are of the other kind.

Of the different groups of Fishes, the *Acanthodians* and *Dipterians* (two families of Ganoids, nearly allied to the *Lepidoids*), and the *Cestracionts* (Placoids), were first introduced, and have been found together in the Old Red Sandstone (Devonian) rocks, and the latter also, though very rarely, in Silurian rocks. The number of species in the older rocks is not considerable, but gradually increases towards the newer beds, and becomes rather numerous in the Carboniferous rocks, several complete genera being introduced and lost during the interval. Amongst these are the singularly formed *Cephalaspids*, the *Pterichthys*, the *Coccosteus*, and others among the Lepidoid group, and also several Sauroid fishes, as *Diplopterus*, *Megalicthys*, and others, while in the Magnesian Limestone, where the Palæozoic rocks terminate, and the Heterocercal fish cease to be exclusively present, the *Pygopterus*, *Acrolepis*, and some other genera of Sauroids, with the *Palæoniscus* (Lepidoid), make their appearance, but are not continued into the secondary rocks.

Taking the different families of fishes, and commencing with the LEPIDOID ganoids, we find that the heterocercal genera, of which there are six (not including the Acanthodians and Dipterians), include four absolutely confined to rocks not newer than the Carboniferous, and two (*Palæoniscus* and *Platysomus*) only just extending into the trias. There are still remaining the whole tribe of homocercals, including ten genera and many species, which are exceedingly common, and highly characteristic of the lias and some newer oolitic beds, extending in one instance (*Lepidotus*) into the chalk. The lias may, however, be regarded as the metropolis of this group; at least thirty-two species being known in the English beds alone, and many others occurring in the lias on the Continent. Of the different genera, *Gyrolepis* is carboniferous and triassic; *Dapedius* and *Tetragonolepis* almost exclusively liassic; *Lepidotus* widely distributed throughout the secondary period; and *Pholidoporus* chiefly Wealden.

The SAUROID, like the Lepidoid family, is widely spread among fossiliferous rocks, and the CŒLACANTHS, in some respect analogous, may be considered as having a similar distribution in time. The heterocercal genera range between the Old Red Sandstone and the Trias; one genus (*Saurichthys*) being triassic exclusively, and others confined to the old red and carboniferous rocks. Of the Cœlacanths there are also several carboniferous and older genera, *Megalicthys* being the most remarkable.

The homocercal Sauroids are chiefly oolitic, where the number of species is exceedingly large. The family of PYCNODONTS are almost all oolitic, but may be considered to range from the trias to chalk. The SCLERODERMS, another family, is found in cretaceous rocks, but extends and is chiefly common in the older tertiaries. The ACCIPENSERIDES (Sturgeons) include one supposed lias genus, and one from the London Clay, besides the existing Sturgeons.

The order of PLACOIDS, divided into seven families, is represented in a fossil state by genera referred to every family but one (*Cyclostoma*). Of these, the most important among existing fishes are those least abundant in a fossil state, and the converse is also true, the *Cestracionts* having only a few living species, while the Rays and Saw-fish are rare among extinct forms.

The oldest placoid fishes are Cestracionts, but the greatest development of the family seems to have taken place about the close of the carboniferous, and commencement of the secondary period, and they are now represented by a single species. The *Hybodonts* commenced in the carboniferous period, and extended only to the cretaceous rocks; but like the Cestracionts, the chief species are triassic and oolitic. Of sharks (*Squaloids*), there are representative forms from the commencement of the carboniferous to the existing period, the cretaceous rocks generally containing perhaps the greatest number, although many teeth are found, and some of gigantic size, in the middle tertiary series. The rays and saw-fish have been found only in tertiary rocks, but the *Chimeroids* appear to have extended over a much wider range, remains having being found occasionally in the carboniferous limestone.

The CTENOID and CYCLOID orders of Agassiz, include a very large proportion of all existing fishes, but not a single species older than the chalk. The Perch family amongst the former, and the Scomber and other families, of which the carp, the pike, and the herring are now well known genera, are those chiefly represented in the ancient seas. It is remarkable, however, that the fossil species are usually of distinct generic character, and not unfrequently form into a group or sub-family, showing some more or less striking peculiarity. Thus, there is a distinct group of perch-like fishes in the cretaceous rocks, having more than seven rays to the branchiostegous ray, and differing absolutely in this point of structure from the existing species. So also the Sparoid fish (Dentex, &c.) are found only fossil in the Monte Bolca (older tertiary) beds. Most of the other Ctenoid, as well as the Cycloid fishes, are represented either by a few species of known genera, or by genera now altogether extinct. Many more are found in the tertiary than the cretaceous rocks, and the beds of Monte Bolca are especially rich in individuals as well as species. The following tabular statement of the distribution of fossil British species determined by M. Agassiz some years ago, will, if not quite accurate, give at least a useful idea of the subject. It must be observed, that the number of British tertiary species is exceedingly small, compared with that from other countries.

TABLE I.—*Grouping of the Species of British Fossil Fishes.*

	Genera.	Species.
CYCLOIDS		86
CTENOIDS		31
PLACOIDS—		
Cestracionts	13	... 83
Hybodonts	5	... 48
Sharks	11	... 26
Rays	7	... 24
Chimeroids	9	... 43
		341

	Genera.	Species.
Brought forward		341
GANOIDS—		
Lepidoids	27	... 116
Sauroids	25	... 74
Cœlacanths	10	... 27
Pycnodonts		84
Scleroderms		6
Sturgeons		2
Total species		650

TABLE II.—*Distribution of British Fossil Fishes in the Principal Groups of Formations.*

TOTAL SPECIES.	Doubtful,* or Ichthyodorulites.	Cestracionts.	Hybodonts.	Sharks.	Rays.	Chimeroids.	Total PLACOIDS.	Lepidoids.	Sauroids.	Cœlacanths.	Picnodonts.	Scleroderms.	Sturgeons.	Total GANOIDS.	CTENOIDS.	CYCLOIDS.
PALÆOZOIC.																
7 Silurian . . .	7	..	..	..	..	..	7	..	..	..	..	..	..	..	..	..
69 Devonian . . .	7	3	..	..	..	..	10	34	13	12	..	..	..	59	..	..
170 Carboniferous .	34	63	10	1	..	..	108	34	14	14	..	..	..	62	..	..
49 Permian . . .	1	10	..	..	..	..	11	24	10	3	1	..	..	38	..	..
SECONDARY.																
63 Triassic series .	6	7	11	..	..	16	40	5	8	1	9	..	..	23	..	..
128 Lias	11	5	5	2	2	..	25	59	41	1	1	..	1	103	..	..
202 Oolitic series . .	19	10	5	5	2	16	57	37	56	3	49	..	..	145	..	..
24 Wealden series .	7	1	4	1	..	..	13	7	..	..	4	..	..	11	..	..
155 Cretaceous series	..	16	1	29	5	..	51	5	8	2	20	6	..	36	19	49
TERTIARY.																
92 Older Tertiary (London clay)	..	..	..	10	19	3	32	..	..	..	10	..	1	11	12	37

161 *Distribution of extinct* MOLLUSCA.—Of the various natural groups of mollusca, or shell-bearing animals, which have left behind them distinct indications of a former state of existence, the *Cephalopoda* are among the most remarkable and abundant, especially in the older and middle series of

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* The species of Placoids thus designated, are determined only from Ichthyodorulites, except in some cases, (especially on the Silurian list,) where they have not yet been referred with certainty to any natural family, and may be either Placoids or Ganoids.

rocks. The *Gasteropoda*, of which the limpets and whelk are examples, and which now include the large tribe of univalve shells, are also well indicated by a vast number of species, while the *Conchifera* (the bivalved-shell animals) are presented in a number of different forms, gradually approximating those of existing species as they approach our own times, but affording in the older rocks generally a singular preponderance of the group called BRACHIOPODA, represented now by the *Terebratula*.

Beginning with those of highest organization, we find the remains of Cephalopoda of simple and long extinct forms in the most ancient of fosiliferous rocks. The genus *Orthoceras*, and others nearly allied, (*Gomphoceras, Cyrtoceras, Phragmoceras*,) are thus enormously developed in the Silurian and Devonian rocks, while *Nautilus, Clymenia*, and afterwards *Goniatites*, present numerous Devonian and Carboniferous species, and a singular preponderance of individuals greatly affecting the physiognomy of the fauna. The nautilus, retaining its general form and structure, was in the secondary period accompanied by the numerous members of the genus *Ammonites*, which, attaining a maximum of development in time towards the latter part of the period, entirely died out before its close. Peculiar forms of the shells of these animals are to a very remarkable degree characteristic of particular beds or groups of beds, and thus in the chalk, the form which at first was a comparatively simple spiral, became greatly varied, and often exceedingly different from the normal type. The genus *Belemnites*, although rather less widely diffused, contains some of the most doubtful and least recognisable of shells, partly from the great simplicity in the external surface and form, and partly from the varieties of growth and accident to which it was subject. No less than twenty-five genera of ancient Cephalopoda have been determined, of which only two are now living, (*Sepia* and *Nautilus*.) and but three additional ones can be found in all tertiary deposits hitherto known. There are nine genera Palæozoic, (seven of them from the lower rocks,) fifteen are lower secondary, and six upper secondary. Of all the genera, *Ammonites* is that most abundantly represented; and it has been found convenient and useful to separate its very numerous species into no less than twenty-one groups, forming seven divisions of the genus, characterized chiefly by the shape of the back of the shell. This division is considered to be natural and gives proof of marked modifications of form, having reference to epochs of time. It was introduced by Von Buch, and has since been slightly modified by M. A. D'Orbigny.

The species of Gasteropodous Mollusks, found in the oldest or Silurian rocks, are comparatively few, and are difficult to determine accurately, although many have been referred to existing genera. The well-known genus *Natica*, the patelliform *Capulus*, and the *Chiton*, are considered to be truly represented in these ancient rocks, but with these there are a number of others, more or less resembling *Littorina, Nerita, Patella, Trochus, Turbo*, and *Turitella*. There are many others to be added to the list.

Taking, however, a wider range, we find amongst the principal genera of these univalve mollusks, only ten acknowledged, and five doubtful ones, in the whole lower Palæozoic group of rocks, and only sixteen admitted, and ten doubtful in the upper Palæozoic series, most of the genera in the older being also included in the newer rocks. Of these, all without exception are marine, some being littoral or inhabit shallows, but most of them occurring in deep water. In the lower secondary rocks we have sometimes thirty-six genera, and in the upper secondary forty-six, while throughout the tertiary rocks the order is represented in 108 genera, including a number of terrestrial and fresh-water species.

The CONCHIFERA, or bivalve mollusks, are very scarce in a fossil state in the oldest fossiliferous rocks, and exhibit some singular and long extinct forms. The *Avicula* and *Pecten* are the first known genera distinctly recognisable, but with them are associated several others, that have been doubt-y, and in many cases wrongly, referred to such groups as those which now include the cockle, the mya, the muscle, &c. It is in the carboniferous limestone that shells of this kind first become common, and Ireland is especially rich in specimens. The species of *Arcaceæ* are especially characteristic of this among the ancient formations, and in the still newer deposits of the Oolitic period, where fossil shells of all kinds are unusually abundant, this family is nearly approximated to the existing divisions. Besides these, we have also in the Oolites species of *Corbula, Porina,* the *Mytilaceæ,* the *Veneridæ,* the *Lucinæ, Astarte, Lima,* and *Crenatula.* 'The genera most developed in British strata are, *Pholadomya,* of which nineteen species are enumerated, *Modiola* (17), *Arca* (23), *Nucula* (11), *Trigonia* (13), *Astarte* (22), *Cardinia* (12), *Cardium* (12), *Isocardia* (11), *Pecten* (31), *Lima* (23), *Gervillia* (10), and *Ostrea* including *Gryphæa* (33). Some genera, of which there are few species, are also highly characteristic, as *Perna* (2), *Pholas* (2), *Panopæa* (several), *Opis* (2), *Myoconcha* (1), *Lysianassa* (4), *Hippopodium* (1), and *Corbis* (3). In the fresh-water beds of the Wealden numerous well-marked species of *Unio* occur, with *Cyclas* and *Dreissena.* The British cretaceous fossils of this family have considerable relations with Oolitic forms, and in some few instances (as *Gervillia aviculoides*) appear to be identical. The greater number occur in the Greensand, or Lower cretaceous series, and indicate the formation of these beds to have been in shallower water than that in which the chalk was deposited. The genera greatly developed are, *Arca* (12), *Nucula* (11), *Trigonia* (12), *Venus* (17), *Inoceramus* (17), *Ostrea* with *Gryphæa* (20), *Lima* (12), *Pecten* (14). The presence of true species of *Crassatella, Cyprina, Cardita, Solen* and *Spondylus,* is worthy of note. *Pholadomya, Panopæa, Corbis, Corbula, Isocardia, Anomia, Avicula, Gervillia, Plicatula* and *Pecten,* have well-marked representations among British crestaceous fossils. *Thetis* is a remarkable genus of this period."*

The Eocene or older tertiaries contain a vast number of species referable to known genera, but all, or almost all of them are now extinct. In the upper tertiaries, a larger proportion of existing species is met with, and the prevailing and characteristic forms assume a much closer resemblance to those found in the vicinity of the spot containing such groups. There are also many generic forms of these shells in foreign beds, not known in our own country, and there appears to be a grouping which gradually resembles that now observable. Many species found fossil on our own shores and belonging to newer tertiary deposits, have also been met with under other circumstances and in distant spots, still living.†

The general character of the bivalves of the middle part of the tertiary series in England is Mediterranean, or rather Lusitanian, and of the newer part, mixed Mediterranean and northern, while still newer beds occur which are essentially northern, and even arctic.‡

The remarkable shell-bearing animals called **Brachiopoda**, although somewhat rarely represented in existing seas, must at one time have played a most important part in the animal economy, and even greatly affected the physiognomy of many ancient and now extinct faunas. They seem to have been the earliest introduced of all mollusca, some species of *Lingula* being the oldest fossils known. They soon and greatly increased, and the typical forms of genera, and more important groups, were at once amongst the most abundant, and the most remarkable of the forms of organic life of which any remains are left.

Of these animals more than 100 species have been determined from British Silurian beds alone, the genus *Orthis* (50 species) being most

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* See the descriptive letter-press attached to the Palæontological Map, by Prof. E. Forbes, in Johnston's *Physical Atlas.*

† This is the case also with the univalves, as a remarkable *Fusus,* (*F. contrarius,*) long supposed to be confined to the fossil beds on the east coast of England, has lately been found occupying a definite position as a recent species on the coast of Spain.

‡ E. Forbes, *ante cit.*

remarkable. *Leptœna* (20 species) is also characteristic, and *Pentamerus* is confined to this group of rocks. *Spirifer*, *Terebratula* and *Atrypa*, *Orbicula* and *Crania*, and a few *Producti* have also been described. In the Devonian period Spirifer increases, *Strigocephalus* replaces *Pentamerus*, *Productus* increases, *Orthis* decreases greatly, *Leptœna* continues, and *Calceola* (a new genus) is added, and is exclusively of this period. In the carboniferous rocks, *Spirifer* and *Productus*, and *Chonetes* with *Terebratula*, include almost the whole number of Brachiopods, which, however, are enormously preponderant in number of individuals in many districts. In the Permian rocks the whole group has fallen back into a few unimportant representatives, thirty-seven species only being known.

The genus *Terebratula* is in a high degree characteristic of the whole secondary period, and only a few *Spirifers*, with *Crania*, *Lingula*, *Orbicula*, *Magas*, and others, interfere with its presence. In the tertiaries, the shells of Brachiopods are almost as rare as in existing seas. A remarkable and anomalous extinct group, which under the name *Rudistes* have attracted much attention, but have not been satisfactorily explained, are peculiar to the rocks of the newer secondary period.

162 *Distribution of extinct* ARTICULATA.—Of this great and important class, now represented by so many thousand species of insects, Cirrhipeds, Annelids, and Crustaceans, but few remains, comparatively speaking, have been found in a fossil state. Some of the few, however, exhibit great interest.

Of Crustaceans, the family of *Trilobites*, now totally absent, seems to have been eminently characteristic of Palæozoic formations. There are several groups, chiefly from the Silurian or lower part of the Palæozoic series, and the species that occur in the Devonian and Carboniferous rocks, are for the most part few in number, and not remarkable for any full representation of individuals, or any marked peculiarity of form, with the exception, indeed, of the genera *Brontes* and *Harpes* (Devonian), and *Griffithides* (Carboniferous). Many other Crustaceans appear in the carboniferous rocks, but they have not been found in sufficient abundance to affect the general character of the group of fossils.

The Oolitic rocks, and indeed all the rocks of the secondary epoch, from the Lias to the Chalk, present numerous and interesting Crustacean remains, many of them peculiar, but all approximating much more to the existing forms than the Trilobites do. The Lias contains several species resembling the lobster and prawn, and these as well as species of crabs, &c., are continued and multiplied in the oolites of England, and the upper oolitic beds from which the celebrated lithographic slate of Solnhofen, in Bavaria, is obtained. Other Crustaceans, both crabs and lobsters, or rather representatives of these tribes, are found occasionally in the lower cretaceous beds. The London Clay, and other tertiary beds, both in England and elsewhere, contain remains of various specific forms still more nearly allied to the inhabitants of the adjacent seas. Some species of small Crustaceans of lower organization, (*Cypris*, &c.), have been met with abundantly in various parts of the newer palæozoic, the secondary, and tertiary series.

INSECTS have left remains in various rocks, but they are generally too ill preserved to enable us to distinguish any very important characters. In the coal measures the body of a scorpion, the remains of wings of flies, and the wing-cases of some beetles have been described, and in the Lias and lower Oolites numerous fragments, generally imperfect, have been the objects of careful examination by Mr. Westwood.* The newer Oolitic and the Wealden deposits present other examples, but it is difficult to refer to fragments so imperfect by very distinct specific characters. In tertiary deposits the remains of such animals become much more abundant, but are chiefly confined to a few localities. The tertiary beds of Aix, in Provence, and of Œningen, the lignites of the neighbourhood of Bonn, and the amber-bearing deposits on the

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* See Brodie's *History of Fossil Insects in the Secondary Rocks of England.*

shores of the Baltic, are the most remarkable and prolific, and have yielded results of some importance to the Entomologist. The following eight principal orders of insects are represented in a fossil state—*Coleoptera* (beetles), *Orthoptera* (locusts), *Neuroptera* (dragon-fly), *Hymenoptera* (Ichneumon-fly), *Hemiptera* (lady-bird), *Lepidoptera* (butterfly), *Diptera* (fly), *Thysanoura* (Podura).

Remains of ANNELIDA are not wanting in a fossil state, but the animals of this tribe being soft, only a few and imperfect indications are usually preserved. In the oldest Silurian rocks, marks have been found which have been referred to worms, and it is not unlikely that similar indications might be found in rocks of almost all ages.

Many worms incase themselves in stone, and thus the shelly tubes in which the animal once lived are very permanent. Since, however, at present, very different species are found to inhabit tubes not to be distinguished from one another, it is clear that not much stress can be laid on evidence derived only from data so little important. The genera *Serpula* and *Ditrupa* are of almost universal occurrence, and probably include a large number of extinct species in all parts of the world and of almost all geological dates.

163 *Distribution of extinct* RADIATA.—Of these animals, the *Echinodermata* and the *Zoophyta* form the two most important groups, and we have in addition to these, the *Amorphozoa*, containing the sponges, of which many are found in a fossil state. Many well marked and peculiar forms occur in a fossil state in rocks of all periods, and many natural families, once enormously abundant, have either entirely disappeared or dwindled down to the most insignificant dimensions.

Of the Echinoderms the most ancient group is that of the *Cystideæ*, closely allied to another group, the *Crinoideæ*, which, as well as the former, is abundantly presented in a fossil state, but very rarely by any existing species. The Cystideans include a number of genera all (with one doubtful exception) Silurian, but the Crinoids are more widely diffused, although these also appear to have commenced their existence at the very earliest introduction of life, and attained their maximum of development during the Carboniferous period. A new and peculiar group (*Pentacrinus*) replaces the older forms in the Lias, and by various species continues into the Chalk. Other, but not numerous, species are also found, the free-swimming forms commencing, and gradually displacing the attached Crinoids. In addition to the Crinoids, the orders of *Ophiuridæ* and *Asteriadæ* (star-fishes) commenced in the oldest period, but appear to have obtained their chief development much later. Star-fishes and true Ophiuræ, as well as Crinoids, have thus a wide range of distribution in time among the large and not unimportant group of animals to which they belong, and in the newer part of the Palæozoic period they began to be accompanied by Echinidæ (sea eggs). The remaining groups of Echinodermata present no hard parts by which their form can be preserved to future ages, and there is thus no evidence of their existence in a fossil state.

The ZOOPHYTA, amongst which are included corals and a multitude of small animals having calcareous skeletons, besides many others which have no solid framework, afford abundant indications of their former existence in rocks of all ages. It appears from the result of observations on these, that 'little if any change has been made in the plan of zoophytic organization since the beginning of geological time; that whilst some genera have passed away and new ones have taken their places, the earliest forms were as perfect as their successors, indeed, among the very earliest, the most perfect forms of zoophytes play as important a part as the most rudimentary. Most of the genera are remarkable for their great duration in time, and this applies also to a great many species both during Palæozoic and Tertiary epochs.'*

There are two divisions of Zoophytes building solid habitations, one of which, the *Bryozoa*, does not really belong to the class, but on account of the

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* E. Forbes, in *Physical Atlas, ante cit.*

extreme similarity of the stony frameworks constructed by its members, they cannot be dissociated from the true polyps constructing corals. Of this division as of the other (the *Polyps*), there are examples in Silurian rocks where the genera *Eschara*, *Flustra*, and others are found. In the same rocks are *Favosites* and *Chætetes*, *Petraia*, *Catenipora*, and *Aulopora*. These, with *Strombodes* and *Syringopora*, give a marked character to the oldest fossiliferous limestones of the Silurian period. Many of the Silurian species extend into Devonian rocks, although many others disappear and are replaced by new forms, and *Astræa*, already introduced, becomes there more abundant. *Cyathophyllum*, *Lithodendron*, and *Lithostrotion* occupy an important place, and with *Gorgonia* attain a maximum in the subsequent or Carboniferous rocks, which are remarkable for the large proportion of coralline limestone of which the lower division is made up.

The Palæozoic zoophytes are quite distinct as a group from the species found in rocks of the secondary period, and some forms, as *Graptolites*, are altogether peculiar to the older epoch. In the lower and middle Oolites, a considerable number of corals occur, *Astræa* being especially rich in species and individuals, though *Turbinolia* is almost equally remarkable. In the cretaceous rocks there are many small corals, most of them Bryozoa, which have not been much examined, and in tertiary formations the number of species is very large, but the condition of the seas in which they lived appears to have greatly differed from that of more ancient periods.

The fossil *Amorphozoa* include chiefly sponges and spongiform bodies, the lowest in organization of all that have been determined. There are a few Silurian and some Devonian species, while others have been observed also in carboniferous rocks, but some of the German localities of Oolitic rocks are far more remarkable than older beds for the presence of such remains. A large number of forms have been described both there and in the newer or cretaceous rocks, the most remarkable genus among the latter being *Ventriculites*, which occurs abundantly among the chalk flints. Tertiary sponges have been described by Michelin and others.

There still remain to be mentioned the two large and doubtful, but not uninteresting, groups, the *Foraminifera* and *Infusoria*, which must be referred to the ZOOPHYTA, and which, although no doubt introduced very early and occurring fossil in Devonian rocks, begin to be important in the newer part of the palæozoic period, especially in Russia. Other species have been found in the lias and oolites, a large number in cretaceous rocks, and an almost infinite multitude in rocks which are perhaps intermediate in age between the secondary and tertiary, as well as in the older tertiary rocks of various parts of Europe and North America. Most of the fossil infusorial animalcules of which remains have been found are in tertiary rocks of comparatively modern date.

164 *Distribution of extinct* PLANTS.—The remains of plants are, as might be expected from the character of most of the deposits, either entirely absent, or confined to a few spots, and only in rocks far removed in point of time. Thus we find such remains chiefly in the rocks of the carboniferous period, but also in the older oolitic rocks in the Wealden and in tertiary deposits. The oldest forms of vegetation are very distinct from those since introduced, and show a remarkable preponderance of ferns, both arborescent and others—at least, this is the case with the carboniferous fossils: and although some species have been referred to Devonian rocks, and fucoids are found occasionally in Silurian limestones and schists, the really important groups are only known in beds associated with coal. With the ferns of this period are dicotyledonous trees allied to pines, and these in the newer beds are accompanied by *Cycadeæ* and true *Coniferæ*, which ranged plentifully during the secondary period in England and Europe. The fossil plants of the London Clay are closely allied to some groups now confined to the East Indian Islands, and probably indicate a warmer climate than at present, and a very different distribution of land.

CHAPTER XIII.

ETHNOLOGY.

§ 165. General nature and meaning of the science of Ethnology. — 166. On specific character. — 167. Divisions and mode of treatment of the subject. — 168. External structural peculiarities of the human race. — 169. Internal structural peculiarities. — 170. Principal varieties of the human race, and their arrangement into distinct groups. — 171. Natural geographical limits of distribution. — 172. Language. — 173. Modification of the races of men. — 174. Mixture of races. — 175. Influence of man on other animals. — 176. Influence of man on inorganic nature and on the vegetable kingdom. — 177. Effect of inorganic nature on man. — 178. Statistics of the human race. — 179. General conclusion.

GENERAL Nature and Meaning of the Science of Ethnology.—No account of the Earth, its inhabitants, and its history—professing to explain the modifications of its surface, and record the revolutions and changes it has undergone—would be in any sense complete without including some notice of the human race and its distribution in various countries, and at various times. The study of this department of Natural History has been designated Ethnology, and the object in the present chapter is to give an outline of the science so named. We must, however, neglect many points of interest, especially those which are connected with the personal and social qualities of the human race, for these in no way affect that natural-history view which solely belongs to Physical Geography.

Considered as a race introduced upon the Earth at a certain period of its history, the human family presents to the careful and philosophic observer an infinite variety of problems, difficult and complicated in the highest degree. Hitherto these problems have received but little attention compared with their real importance, and the growing interest felt in reference to them within the last half century has hardly yet spread to the mass of society, who are apt to shelter themselves under doubtful histories, and the general but vague ideas derived from very imperfect knowledge. The most that we can here attempt, however, will be to state a few of the problems, and point to the various attempts made for their solution or illustration.

The subjects that offer themselves for consideration in the strictly natural-history study of the human race, are chiefly those connected with colour and other external peculiarities, internal structure, language, and intellectual development. These all involve to some extent positive facts, and hence we may, with some satisfaction, discover by their means the degree of affinity that may exist amongst the principal divisions of men; but the real importance and relative value, even of these facts themselves, can only be appreciated by careful study.

It may perhaps be considered, that the inquiries of chief importance, and those which, when answered, promise the greatest results, have reference to (1) the specific identity of those various races of men which differ most from each other, and which being found inhabiting districts naturally distinct, may be regarded to some extent as typical races—(2) the degree to which mixtures of these races can produce other and permanent varieties—(3) the extent to which such mixtures as have been already produced can be traced back—(4) the absolute period during which the human race has been actually present, not only on the globe in general, but in particular countries—and (5) the true amount of influence that man, in an uncivilized or civilized state, has upon the distribution of other families of his own kind, and upon other organic beings. These are points fairly within the inquiry of the naturalist, and demand therefore notice in this place.

166 *Specific Character.*—In considering such points we are forced to pay some attention to another question that has long been a source of dispute—namely, what is to be understood by the term *species*, and how far varieties may extend without reaching to specific difference. In man, as in other animals of high and complex organization, capable of adapting themselves to great changes of temperature and climate, living at one time under the burning rays of a tropical sun, and at others enduring a three or four months perpetual night and frost near the poles, there must occur many modifications of habit at least, if not of structure, which manifestly involve no departure from the normal type. But because this is the case, we are by no means justified in assuming that such differences of habit can involve real and permanent modification of structure, for such a conclusion could only with propriety be admitted, if it were supported by many analogies derived from other natural-history facts, directly bearing upon the point. Too little attention has often been paid to natural-history and common-sense views on this subject, and to the laws of analogy and affinity of distribution and limitation of species of other animals, in deciding on the probable origin of the human race, and the date of this event.

It has, indeed, been usual to assume, as the definition of species, that 'the faculty of procreating a fertile offspring constitutes identity of species, and that all differences of structure and external appearance compatible therewith, are solely the effects resulting from variety of climate, food, or accident, consequently are forms of mere varieties, or of races of one common species.'* It may, however, be safely asserted, that any argument concerning the origin of the human race derived from this definition is vicious, for the whole point in question is assumed, and there seems no doubt that several of those groups of other animals best determined, and most universally allowed to be distinct, may naturally breed together, and do produce hybrids capable of continuing a race, and exhibiting some peculiarities of each of the tribes from which they are derived. Thus, various tribes of wild *felidæ* breed with each other; goats breed with sheep; common cattle with the Zebu, and other well marked species; and the common hare with the rabbit, and also with the hares of other countries, exhibiting examples of no slight importance, where fertile hybrids have been produced by mixtures of well marked species, although new races have not been established. In all these cases, as, indeed, in any single family of any animal, a certain amount of mixture of blood is required to keep up a healthy race, and it may even be necessary to revert to the original stock for such purpose, but this does not interfere with the important conclusion that such mixtures of species are, to a certain extent, natural and are essentially prolific.

In spite of this, notwithstanding such occasional exceptions to the usual sterility of hybrids, it is still, however, very clear, that there must be some provision in the constitution of organized beings tending, under ordinary circumstances, to keep breeds distinct, and prevent the amalgamation of really natural groups. In other words, though species may not be strictly determinable by the test of unfertile hybrids, there still are true specific distinctions preserved unbroken and unmixed with singular tenacity. It is of the highest importance for naturalists to determine, if possible, the nature of these distinctions, and how far any of them are universally applicable; but we are bound to admit that those who pursue the higher departments of Philosophical Zoology, have as yet failed in assisting the progress of natural history by the discovery of any such characteristics.†

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* Hamilton Smith, *Natural History of the Human Species*, p. 114.

† We quote from a very recent work by Alexander Von Humboldt the following additional evidence on this subject of the fertility of hybrids:—'The Canadian bison can be trained to agricultural labour. It breeds with the European cattle, but it was long uncertain whether the hybrid was fruitful. Albert Gallatin, who, before he came forward in Europe as a distinguished diplomatist, had obtained, by personal inspection, great knowledge of the uncultivated

167 *Divisions and Mode of Treatment of the Subject.*—Ethnology, therefore, or the physical history of the human race, cannot obtain from general natural history a decisive answer, even to those inquiries which properly and necessarily belong to that science; and it therefore calls for assistance from many other departments of knowledge. In the present outline, we may with advantage consider, first, that portion of the physical view of the human species which is more directly connected with zoology, comparative anatomy, and comparative physiology. When in this way some idea is communicated of the more elementary facts, we may proceed to consider very generally those points of comparative philology, and afterwards of general human history, which bear upon the questions we have to discuss. Having thus determined the natural-history facts of our race, it will be useful to consider the influence of the human species on inorganic and organic nature, and conversely the influence of external nature on the human family under various circumstances of temperature, climate, and civilization. It is true that in this sketch many details of great importance may be omitted, while, on the other hand, opportunities will be afforded for lamenting the almost total absence of great classes of facts; but perhaps also this may be useful in directing attention to the present state of knowledge on so important a subject.

168 *External Structural Peculiarities of the Human Race.*—Those marked peculiarities of men that are continued from generation to generation without change, and seem at length to be absolutely unchangeable, relate chiefly to colour, hair, and external form, but also include some striking anatomical characters of great importance. Thus, permanent varieties in stature, in the proportions of the limbs, in the form of the pelvis, and in the form and proportions of the cranium, are so numerous and distinct as to separate at once the different families of men into several groups.

The earliest recorded accounts that have survived the destruction of written documents and oral tradition, seem to point to the existence of races of men attaining in former times more gigantic dimensions than at present; and however exaggerated and distorted the accounts may be, they yet seem sufficient to justify a conclusion, that the early conquerors in Asia Minor, and Southern as well as Northern Europe, may have exceeded the original races in respect of height, as much as they certainly did in vigour of character and physical energy. The only race, however, that can now be referred to as showing any distinct evidence on the subject is that which has been described in Patagonia, and which, like others, must soon give way to the encroachment of the white man; but still showing superiority of form when compared, not merely with the stunted and ill-developed Fuegians about them, but even when placed side by side with Europeans of full vigour and ample proportions. This is stated by all travellers of credit, and must certainly be admitted. Many instances, however, are on record of individuals in all countries attaining even a more considerable stature; and amongst them we may mention the case of a Swede, one of Frederick the Great's gigantic guards, described by Haller as being eight and a half feet high, while several Irishmen have been known to attain the height of seven to eight feet; and one, whose skeleton is now in the Museum of the College of Surgeons, and who died, aged twenty-two, in 1783, measured eight feet four inches.

Notwithstanding these exceptions of individuals and races, there is certainly no evidence of any great deviation from the average standard that

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parts of the United States, assures us that 'the mixed breed was quite common fifty years ago in some of the north-western counties of Virginia; and the cows, the issues of that mixture, propagated like all others.' 'I do not remember,' he adds, 'the grown bison being tamed, but sometimes young bison calves were caught by dogs, and were brought up and driven out with the European cows.' At Monongahela, all the cattle were for a long time of this mixed breed, but complaints were made that they gave very little milk.' We believe no one ever questioned the specific distinctions between the European breed of cattle and the bison.

cannot well be referred to local circumstances, but as little doubt can there be that various races do present different average stature. Thus, the Patagonians, inhabiting the southern extremity of South America, are beyond all question an eminently tall race, while the Bosjesmans of the Cape of Good Hope, and the neighbouring country, are as strikingly below the average stature. Nor is intellectual cultivation by any means concerned in this matter, since the native Australians, the nearest in point of low intellectual powers to the South African dwarfish tribes, are, on the contrary, a tall race; while the stunted Fuegians, the race nearest in position to the lofty Patagonians, and the Caffres, inhabiting the country near the Bosjesmans, differ but little in civilization from their dwarf neighbours.

Although it is certain that great differences in stature are capable, under favourable circumstances, of producing permanent varieties without reference to climate, yet it has been considered that this latter also may have some effect. The point is one of some little importance, especially in considering the average height of races taken fairly from a sufficient number of observations; but facts are wanting to found any certain argument with reference to this subject.

If there is difficulty in judging of unity of race by the average stature, it will readily be understood that other dimensions are still less useful in this respect. A considerable difference, however, may be traced in the development of various races, though insufficient to justify important generalizations.

Other external characters of the human race are found in the form of particular parts, some tribes having the head flattened in a remarkable manner, others having the bones of the extremities more or less developed, some possessing thick lips, others small ears, others high cheek bones, while a vast variety of less important differences characterise particular groups, according to some temporary or local circumstances. Many of these depend directly on internal structure, while others, such as colour, are exclusively superficial, although sufficiently important to require careful and minute attention. The nature and condition of the hair afford other external characteristics of singular value, and thus hair and colour are usually considered as the most direct and ready means of grouping the different varieties of the human race into large natural families.

The peculiarities of colour presented in man are chiefly four—white, yellow, red, and black, but each of these admits of a vast variety of shades. The white is often varied with delicate shades of pink, and passes also into tawny and olive coloured. The yellow passes into copper coloured on the one hand, and black, on the other. The copper colour also admits of many varieties, and even black is often presented of different shades in the various members of the same great natural family. All these colours are liable to what are called *albino* varieties.

Of the whole population of the world, a very large proportion, including almost all the inhabitants of tropical countries, exhibit tints of colour approximating them more or less closely to black. These have generally black hair and dark eyes, the hue of the skin being less decided than that of the hair and iris. Where the black is combined with red, as in the indigenous copper coloured races of America, the hair does not cover any part of the face, and in some parts of Africa the hair is not only black, but is crisp, woolly, and short, presenting very marked and permanent characteristics.

The white and yellow varieties of men generally present a fair complexion, assuming a red or tawny tint on exposure to sunlight, and accompanied by hair of light brown, auburn, yellow, or red colour, and eyes either grey, azure blue, brown, or some shade of yellowish or greenish brown, or greenish yellow. These colours of the eye are often found in individuals not presenting the true characteristics of skin and hair, but in great masses of men not exhibiting recent mixture of race one prevailing tint may generally be recognised.

The term albino is applied to individual cases occurring from time to time in all countries, although chiefly noticeable among Negroes, owing to the marked contrast then presented to the ordinary condition. The characteristic of this variety is, that the hair and skin are perfectly white, without a tinge of colour, and the iris of the eye red. Races of albinos have been described in some parts of the interior of Africa, but they probably do not extend to more than a few families in particular villages. The persons thus characterized are frequently the offspring of parents whose other children do not present the same peculiarities.

Before concluding this account of external structure, it is necessary to refer to varieties of form presented by the face, and especially the lips and nose, which are amongst the more distinctly marked characteristics in the Negro race, the Chinese, the Malays, and some of the Americans. The form and position of the ears is also a point worthy of remark.

169 *Internal Structural Peculiarities.*—The form and proportions of the human cranium exhibit differences so marked, and so greatly affecting the intellectual development and capacity for civilization of the inhabitants of different countries, that the assistance of anatomy in this matter is of the highest importance to the progress of Ethnology, and lately also it has been found that peculiarities of structure corresponding to these are to be met with in the figure and proportions of the pelvis. It is necessary, therefore, to consider the facts that are most important in each case.

The cranium is a hollow bone peculiar to vertebrated animals, and forms the protective investment of the brain, on which it is moulded, and the form of which, in warm-blooded animals, it represents. It contains in its walls the organs of hearing, and contributes to form the orbits of the eye, the nostrils, and the face. It is built up of eight bones which are not firmly connected till some time after birth, so that there is a certain amount of flexibility, admitting of great change of general form and proportions by continued artificial pressure.

The first attempt to point out distinctive characters in skulls was that of the anatomist Camper, who based his conclusions on the shape of the skull and the measurement of the angle (called the facial angle) included between two lines, one drawn from the passage of the ear to the base of the nose, and the other slanting from the forehead to the most prominent part of the upper jaw-bone. This angle was thought to afford a measure of the capacity of the fore part of the skull and of the size of the corresponding portion of the brain, and in this way the skull of Europeans when measured gave an angle of 80°, that of a Kalmuk 75°, and that of a Negro only 70°. He also observed that there are forms of the head in which the angle appeared to be greater than it is in the European, and others in which it is less than in the Negro, the former being the ideal heroic heads of the ancient Grecian deities, and the latter being animals of inferior organization, the ape having the greatest angle, but not exceeding 64°. It must, however, be remarked, that in this measurement the apparent gradation from the Negro to the ape is not real, as if the skulls are taken from animals of full age in which the dentition is complete and the jaws completely developed, the angle is not more in the orang or satyr than 30°, and in the troglodyte only reaches 35. In the comparison of skulls, one important point has also sometimes been overlooked—namely, the form of the base of the skull, on which depends much of the general measurement of the angles.

Besides the facial angle, there are other points of difference seen in comparing the skulls of different races; for while some skulls are round and symmetrical, with a broad smooth forehead, others, again, are square, or nearly so, others pyramidal, others narrow and laterally compressed; while ll these varieties naturally induce very marked external peculiarities corresponding to them. Almost all the anomalous and even monstrous divergencies from the normal type in man are capable of being transmitted to posterity, and thus the races amongst whom flatness of the head or any other deformity is regarded as a beauty, exhibit the corresponding form in the heads of very young infants, even when no mechanical pressure has been induced.

One of the most important varieties in the structure of different races consists in a peculiar conformation of the pelvis, and this has recently been the subject of careful investigation by Dr. Vrolik, of Amsterdam, who has examined and described minutely the details observable in skeletons of Europeans, Negroes, and Javanese of both sexes, a female of the Bosjesmans race, and a person of mixed breed.

The important result of these investigations seems to be, that, although the proportions of the bones in this region in Europeans are very different in the two sexes, the difference is much greater between the male and female Negro, the former exhibiting remarkable strength and density, while the latter, in the same race, combines lightness of substance and delicacy of form and structure. The Javanese of both sexes appear to possess a pelvis of peculiar lightness of substance and smallness of size, while the female Bosjesman exhibits, in a most exaggerated form, the narrowness and elongation remarkable in the Negress, and apparently approaches to the structure of the chimpanzee and the orang.

Other observations on the pelvis, by Professor Weber, would tend to show that all varieties of form in the pelvis may be described as belonging to one of four kinds—the oval, the round, the square, and the wedge-shaped, of each of which examples are found in most countries. The form that is most usual among Europeans is the oval, that of the Americans the round, that of the Mongols the square, and that of the different races of Negroes the oblong.

Other structural peculiarities are seen in the bones of the extremities, which in the Negro and some uncivilized races are comparatively elongated and straggling, crooked and badly formed. Thus the tibia and fibula in the Negro are more convex in front than in Europeans, the calves of the legs very high, the feet and hands flat, the heel-bone flat and continued nearly in a straight line with the other bones of the foot, and the foot itself remarkably broad. The fore arm is also much longer in proportion to the body than in other races, and the head is placed further backward on the vertebral column.

170 *The Principal Varieties of the Human Race and their Arrangement into Distinct Groups.*—Although the peculiarities mentioned in the preceding section are none of them strictly confined to special races, still they are so far characteristic that by their means we can with some degree of reason speak of the white, black, copper-coloured, and other races, without fear of being misunderstood, and we may also subdivide these into woolly-haired, black-haired, beardless, and others. But when connecting these so far natural groups with those which, according to the records of human history, have dwelt in, or emigrated from, special countries, there are immediately introduced various elements of confusion, preventing any possibility of subdivision into tribes without the assumption of so much, that fiction soon takes the place of fact. It is evident that the space devoted to the subject of Ethnology in these chapters will by no means admit of the discussion of any views, and we can only put before the reader, as a conclusion, the arrangement that has seemed most convenient and most useful.

Among the various points of difference that might be assumed to assist in the arrangement of the tribes of men, the form of the skull, combined with the colour of the skin and hair, the texture of the hair, and the form and proportions of the pelvis, agree for the most part in marking at least three groups possessed of the extremes of difference in these respects, and not ill supported by historic testimony. It has, indeed, been usual to admit of five principal or typical stocks of this kind, but, perhaps, two of these are more properly considered as sub-typical, at least in the present condition of our knowledge. The three groups thus suggested may be called the CAUCASIAN, or bearded type; the MONGOLIC, or beardless type; and the woolly-haired, or NEGRO type. The Europeans generally may be considered as representing the former; the Tartars, Chinese, and other inhabitants of Central Asia, the native tribes of America, and the inhabitants of Australia, the second; and the Africans the third.

The characteristics of the three principal types may be thus described:—

1. The CAUCASIAN Type.—This typical group has received its name from the idea of its having originated in the mountains of the Caucasus, whence it has spread in Europe and Asia. All the civilized nations of the West belong to it, and it has generally obtained absolute domination when families have migrated to distant countries. It admits of many and very important subdivisions.

The races thus designated are for the most part white, but include tribes of almost every shade towards absolute blackness. The hair is abundant on the head, varying from the deepest brown, and even black, to auburn, yellow, and fiery red, and becoming grey with age. In all the races, the males have decided beard, often spreading over the upper lip and fringing the sides of the face, being, in such case, crisp, curly, or undulating, and not lank. The hair usually harmonizes with the complexion, and that of the head and face have nearly the same colour.

The skull of the Caucasian tribes is larger in proportion than in the others —it is oblong and rounded, and the facial angle rises from 75° to nearly 90°. Its volume amounts to from 75 to 109 cubic inches. The mouth is small, the teeth vertical, the lips graceful and not tumid, the cheek bones not projecting, the chin full and round. The shoulders are ample, the chest broad, the ribs firm, and the loins well turned; the thighs and the calves of the legs symmetrical, and the whole frame constructed for the endurance of toil, and with physical powers equal to the intellectual organization, combining more than any other race strength of limb with activity, and enduring with ease the greatest vicissitudes of climate and temperature.

The people thus characterized include the inhabitants of the great river-valleys of Southern and Western Asia, and all the inhabitants of Europe, except the Laplanders, the Finns, the Magyars, and some other eastern tribes. A large part of North America and many portions of South America are also now peopled with the descendants of the Western Europeans who have migrated in a civilized state.

2. The MONGOLIC Type.—The races that belong to this class differ both from the Caucasian and Negro stock in many highly important physical and intellectual qualities. The skull is small, the facial angle 70°—80°, the contents of the cerebral chamber 69 to 83 cubic inches; the face is flat, the cheek bones projecting laterally, the eyes small and obliquely placed; the hair coarse, lank, and black; the beard scanty, not curly, and not covering much beyond the chin. The nose is small and pointed, and the mouth well formed. The colour of the skin yellow of all shades, rarely passing into white, on the one hand, or black, on the other. The typical races are square of body, low in stature, having the trunk long, the extremities comparatively short, and the wrists and ankles weak.

The people chiefly exhibiting these peculiarities of structure are the Central and Northern Asiatics, the Finns and Laplanders in North Europe, and the Magyars of Hungary. The Chinese and Japanese, and the various Tahtar tribes are the most numerous and characteristic of these races at present. The Esquimaux also belong to them.

The Indian tribes inhabiting North America approach the true Mongols, and may be regarded as subtypical, presenting some points of resemblance to the aberrant tribes of Caucasians. In these, however, the colour is more deeply red or copper-coloured, the cheek bones more rounded and not projecting laterally, the face broader, the forehead low, and the skull less pyramidal.

Another remarkable and very large natural group, the Malays, may be also considered as forming a connecting link between the Mongol and Caucasian types. The Malay tribes have generally a small head, measuring from 64 to 89 cubic inches—the forehead is low, the face flat and broad, the nose short, the mouth wide, and the upper jaws projecting. The hair is generally coarse, the skin varying in colour from clear brown to dark clove, the beard scanty, and the frame slight, except when a mixture with Caucasian blood can be traced. As a people, they are apt to be treacherous, implacable, and ferocious, and they are chiefly confined to the coast, and some of the islands of the Indian Archipelago, excluding parts of Papua and some parts of Australia.

3. The NEGRO Type.—The woolly-haired stock properly designated by this name predominate in Africa. They present many marked peculiarities, amongst which may be mentioned a small facial angle, varying from 65° to 70°, a small head laterally compressed, a narrow depressed forehead, a broad crushed nose, a protruding lower jaw, a wide mouth with thick lips, and large solid teeth, with the incisors placed, not vertical, but obliquely forwards. Besides these characteristics, we find the hair frizzled, coarse, and though not really wool, simulating the appearance of it. The body is often extremely muscular, and exhibits perfect physical development, but the humerus is shorter, and the fore arm proportionably longer than in Caucasian skeletons. The legs and feet are inelegant, the wrists and ankles robust, and the hands coarse. The skin is generally dark-coloured, but very often jet black. Intellectually, they do not occupy a high position among the races of men, thought being habitually dormant, and there being in most cases an almost peurile love for musical sounds. An important and highly interesting branch of this variety occurs in Western Asia, in what is sometimes called the *Semitic race*, including the Assyrians and Babylonians, now almost extinct, the Jews, the Arabs, and the Ethiopians.

All these well marked varieties of the human race, and a large number of others less distinctly characterised, have certainly been in existence on the Earth for a very long period, since in paintings and sculptures made by the Egyptians more than three thousand years ago they were as strongly indicated as at this day. It is certain, too, that the differences are not entirely caused by climate, if, indeed, they are at all dependent on that as an agent, but we are not at present in a condition to explain the real origin of the peculiarities of structure observed, or refer them to any reasonable and probable source.

171 *Natural Geographical Limits of Distribution.*—The various tribes of men, in different countries, appear in most cases to have had definite limits, corresponding to those of certain groups of animals, and although individuals and hordes have wandered to distant countries, and settling there, have exposed themselves to the influence of different climates and habits, they have yet retained their peculiarities of structure. It is therefore important to consider, as far as possible, the chief groups in relation to the country where they now exist, or whence they have migrated.

The Arabs and the Egyptians are two examples of contiguous races belonging to the same family, but exhibiting marked differences, the former occurring in Asia, and the latter in Africa; the former adjacent to the civilized countries of the East, among whom the Hindoos, the Persians, the Armenians, and others, are well known examples; while the latter border on the Negro tribes. Dr. Prichard has remarked, that 'though inhabiting, from time immemorial, regions in juxtaposition and almost contiguous to each other, no two races of men can be more strongly contrasted than were the ancient Egyptian and the Syro-Arabian races: one nation full of energy, of restless activity, changing many times their manner of existence,—sometimes nomadic, feeding their flocks in desert places, now settled and cultivating the Earth, and filling their land with populous villages, and towns, and fenced cities,—then spreading themselves, impelled by the love of glory and zeal of proselytism, over distant countries; the other reposing ever in luxurious ease and wealth, on the rich soil watered by their slimy river, never quitting it for a foreign clime, or displaying, unless forced, the least change in their position or habits of life.'* The differences thus indicated

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* Prichard's *Natural History of Man*, 3rd edition, p. 150.

were carried out also in detail, and nearly correspond to the conditions of the two countries in all respects of Physical Geography, and thus it is, that the natural configuration of a district may and does exercise an important influence on the growth and development of the human race therein.

It has been customary to consider the different races of men as proceeding originally from certain lofty mountain chains as their original habitat, and in this way the Caucasians and the Mongols have been so named, because the one race was supposed to be derived from the lofty mountain chain of the Caucasus, between the Black Sea and the Caspian, and the other from the loftier chain of the Altai, peopled in its higher plains by the Mongols. So also the Negroes have been supposed to be derived from the southern face of the Atlas mountains. This view, however, is not supported by facts, at least so far as history can adduce them. It is more probable that the principal races have flourished and obtained their peculiarities in great river valleys, as that of the Euphrates, the Indus, the Ganges, the Nile, the rivers of China, and others in the Old World, or in great fertile plains, or extensive tracts of country, abounding in herds of deer and cattle; while others have adapted themselves to circumstances in smaller areas, and formed fishing tribes, hunting tribes, or mountaineers of various degrees of interest and importance.

To trace the geographical range and limits of each race now recognised as aboriginal, would occupy too much space, and we must refer the reader for such information to the work of Dr. Prichard, already quoted, and to that of Colonel Hamilton Smith, recently published, *On the Natural History of the Human Species*. It will be useful to illustrate the subject by a few examples, drawn from the distribution of races in Europe, and especially in those countries in which we, as Englishmen, must feel the greatest interest.*

It is now almost universally admitted, that the European nations are a series of colonies of what is called the Arian† race, but under what circumstances, and by what path they originally passed into Europe, can only be a matter of conjecture. It has been considered probable that the northern nations of Europe took their way through the regions which lie to the northward of the Caspian, reaching in this manner the mouth of the Danube, and spreading then towards the north. The Italian, Hellenic, and Illyrian races, on the other hand, probably arrived by a different route—namely, through Asia Minor and across the Bosphorus.

Of the different European nations, which may be regarded as derived from branches of one original stock, we must look upon those which were driven most to the west as the oldest, and thus begin with the Celtic nations, including two branches, one represented by the Irish, Scotch, and Manx, and the other by the Welsh and Bretons, and the early inhabitants of Spain. Next in order comes the Germanic family, consisting of the Northmen, ancestors of the Icelanders, Norwegians, Swedes, and Danes; and the Teutonic stock, in its three subdivisions of Saxon, German, and Gothic. Next are tribes inhabiting Lithuania; and then the Slavonic race, of which there are two branches, the Western or Proper Slavic, including the Poles, Bohemians, and tribes near the Baltic, and the Eastern branch, comprehending the Russians, Servians, and other allied families.

South Europe seems to have modified the migrating races in a different way, and presents the old Italians, the Tuscans, the Thracians, the Arnaouts and Albanians, and the ancient Hellenic race.

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* While these sheets were passing through the press, a work has been published by Dr. Latham, (*The Natural History of the Varieties of Man*, 1 vol. 8vo,) which may safely be recommended to the student as the soundest and clearest enunciation of the most advanced and scientific views of Ethnologists.

† The name 'Aryas' is the ancient national designation both of the Persian and Indian branch of the great Asiatic source of the races that now overspread Europe and Southern Asia, and the derived races have thence been called 'Arian.' The name was adopted by the Medes, and has been handed down by the Greeks.

It still, however, remains doubtful whether these races, whose history can be to a certain extent traced, and which present distinctly their relations to each other, and to the original stock, were really the earliest tenants of these countries. The more probable hypothesis is, that there were still earlier tribes, and in the case of our own country there is not wanting distinct evidence in proof of its having been the habitation of man very long before the earliest introduction of that tribe of Celts who have often been regarded as the first settlers.

If we look to the evidence that exists concerning the actual distribution of these races, we shall find them greatly but not entirely limited by mountains and rivers; each tribe seems to have had a nucleus in the newly discovered, or newly conquered tract, while from this nucleus they at first diverged to occupy a certain area, and finally migrated in part to carry the advance that had been made in civilization to a fresh spot, where the highest advance that had been made in the mother country served as the starting point for the young hordes. Thus it is, that in mountainous countries we still find kingdoms and portions of highly civilized countries, presenting in their population the most marked differences, and even contrasts, while over other far larger but level tracts, a perfect uniformity and monotony of national character prevails, often exceedingly unfavourable to the progress of civilization.

It has already been stated, that the Caucasian tribes occupy all Europe, with the exception of Finmark, Lapland, and part of Hungary. They also now occupy part of North Africa, Persia, the whole of India, the United States and British possessions of North America, a very large part of South America, and many portions of Australia. A part of South Africa, and a multitude of islands in the Pacific Ocean, have also been colonized by them in recent times, and thus the Western Caucasian varieties are now spread over the globe, and have in many cases almost driven out the original races.

When we regard the whole Earth, and consider what is known of the physical geography and climate in every country, there will often appear some distinct natural reason for the spread of particular races in the directions we may trace them. Thus, the Caucasians occupy, and have occupied for a very long period, the great fertile valleys and plains of the temperate zone, and the more habitable countries in the torrid zone, at least so far as the Old World is concerned; while the Negroes have been chiefly confined to the waste and unfertile deserts and other lands of tropical and Southern Africa; and the Mongols to the table-lands, mountains, and valleys of Northern Asia, America, and Australia. The greatest populations are generally found on the banks and mouths of rivers, on the shores of gulfs and great inland seas, and thence the races have generally extended up the country, following the course of the streams, and strictly limited by great and rapid rivers, which have thus proved effectual natural barriers. Men, indeed, in a natural state, are subjected to laws of distribution like other animals—they spread where means of subsistence and shelter offer themselves, they multiply in the most favourable spots, they stop where there is no longer any inducement to go on; but this is not the case when races become able by mechanical ingenuity to overcome natural difficulties; and thus the spread of civilized nations, and their limits of distribution, offer no parallel, and are bounded by no such checks as those which, up to a certain point in cultivation, have proved absolute. Still, early impressions have never yet been effaced. Penetrating through the surface on the smallest occasion of extraordinary excitement, we are able to perceive the marked national characteristics in almost every people, whether we look at races derived from a multitude of sources like our own, or those compounded only of two or three—whether we regard the half-breeds between the Negro and Caucasian, or the Caucasian and Mongolic, or look at the nearly pure descents of the higher castes of the Hindoo. Government has no power of uniting races whose blood is different—language may conceal for a time, but cannot obliterate these permanent characters; and for at least thirty centuries there have been as well marked and important distinctions between the bearded and the beardless man, the red man and the white, and the true Ethiopian and the Negro, as there are at this day, while the essential points of distinction are as clear now as they were at that distant period.

172 *Language.* — Of all characteristics presented by the different races of men, and depending on the higher or intellectual part of his nature, none is more useful in determining disputed points as to the origin of particular tribes than the careful study and comparison of the words and grammatical construction employed to express the wants and feelings of our nature. The study of language must, therefore, go hand in hand with that of physical peculiarities and human history, and though, as we shall see, not absolutely to be depended on or trusted, when it affords only negative results, or to be taken without hesitation even when resemblances can be traced, still it must always have great weight in the mind of any unprejudiced person.

It is generally agreed, that the most extensive relations between languages, and those least likely to be effaced by time and foreign intercourse, are the fundamental laws of construction, both in words and sentences. Construction, indeed, or the rules which govern the relations of words in sentences, seems especially enduring and constant, since similarity in this respect prevails through whole classes of languages which now have few words in common, though they appear originally to have had more. But beyond this, there is a cognate character in words themselves, which sometimes pervades the entire vocabulary of a whole family of languages, the words being formed in the same manner and according to the same artificial rule. This is illustrated in the monosyllabic structure of the Chinese and Indo-Chinese languages, while a remarkable instance of grammatical analogy is to be found in each of the two systems of the Indo-European languages, of which the Greek and English are respectively examples.

It has, indeed, been doubted whether analogy of structure alone is sufficient to prove community of origin of different languages, when unsupported by similar words, as it would seem that languages really descended from the same stock must exhibit their origin in both ways. It is, however, certain that such words may be very few in number, as will be seen if we compare the Welsh and Russian tongues, which are singularly unlike in this respect; while, on the other hand, a large number of words being introduced does not prove the languages to be of cognate origin. The evidence to be deduced from verbal analogies depends, however, much on the classes of words in which such analogy is to be traced, and the words that resemble each other in languages derived from the same stock are very different from those borrowed after the two languages are formed. There is, for example, a kind of domestic vocabulary in the first case, which includes the simplest family relations, 'father,' 'mother,' &c., together with the names of various parts of the body, of the most essential and manifest material and visible objects, and of domestic animals, besides some verbs expressive of universal bodily acts, many personal pronouns, and the numerals, at least to a certain smallextent.

On the other hand, there are words belonging to a certain degree of civilization, and connected with the simple arts (*e. g.* to plough, to weave, to sew, &c., and the names of weapons, tools, and dress), which are often common to nations whose domestic vocabularies are different, and different when the domestic vocabulary is nearly the same. It will also be evident that many words indicative of intellectual improvement, moral cultivation, religion, and other matters, will be occasionally borrowed by a nation during its progress in civilization, and often from people who from any accident have influence, although they may belong to a different stock. Thus, the New Zealanders will acquire a multitude of English words, although no relation may be traceable between the roots of their languages and the English, nor its earlier and domestic vocabulary.

The various languages of the Earth have been grouped into four:— 1. The Indo-European languages. 2. The Turanian, or languages of High

Asia, and other regions to be pointed out. 3. The Chinese and Indo-Chinese, a monosyllabic and uninflected language. 4. The Syro-Arabian, or Semitic.

The Indo-European languages are the national idioms of all those races who at the time of Cyrus became, and have ever since continued to be, the dominant nations of the world, except where Mahommedan fanaticism has recovered for the Mongol and Negro races some sway over the weaker divisions of the Indo-European tribes. There are many groups of these languages, each group including a large number of dialects. The eastern group comprehends the ancient Persian idioms, the Sanskrit and the Pali of India. The western group, the Greek, the old Illyrian or Albanian, the old Italic language excluding the Etruscan, the old Prussian, the German, the Slavonian, and the Celtic: these are all very distinct and of very ancient date.

Now, it becomes very naturally a question, since no one conquering nation could introduce at once so many languages, whether the different nations were kindred tribes of some primitive stock, and derived the analogies of their speech from some common language which had gradually deviated from original identity by variations at first merely of dialect, but gradually increasing; or whether the facts will admit of any other explanation. It seems clear, that there is no other, and, indeed, there is internal evidence in the Indo-European languages themselves, sufficient to prove, that they did grow by gradual dialectic development out of one common matrix. 'Any one who possesses competent knowledge of these languages, and considers the nature of their relations to each other, the fact that the original roots are for the most part common, and that in the great system of grammatical inflection pervading all these languages there is nothing else than the varied development of common principles, must be convinced that the differences between them are but the result of the gradual deviation of one common language into a multitude of diverging dialects, and the ultimate conclusion forced upon us is, that the Indo-European nations are the descendants of one original people, and consequently, that the varieties of complexion, form, stature, and other physical qualities which exist among them are the results of deviation from an original type."*

The groups of languages referable to the second great family of European and Asiatic nations, differ in some fundamental points from that of the Indo-European race, and assist in this way to support the conclusion, which is indeed forced upon us by other evidence, that these races had overrun many parts of Europe, very far to the west, long before even the oldest of the races now existing were at all introduced. The languages are remarkable as having nouns nearly or wholly without inflexion or variation of case, number, or sex, which can only be expressed by appending additional words, and exhibiting these auxiliaries, and any possessive and relative pronouns of other languages as suffixes, or syllables placed after the words which they modify.

Of all the tribes possessing these languages, two only, with the exception of the Finns and Lapps, have effected a lodgment in Europe in such a way as to perpetuate to the present time any physical evidence of their former existence. These are the Magyars and the Basques. There are also phenomena in the Finnish, Lappish, and Celtic languages, which appear to render probable a former admixture with races which are now totally extinct.

Another family of languages belonging to the great continent is the Chinese, which, with its various Indo-Chinese dialects, consists of monosyllabic roots, not becoming dissyllabic by construction. These languages are not only incapable of inflexion, but do not admit the use of particles as a supplement to this defect, the position of words and sentences being the

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* 'Report on Ethnology,' by Dr. Prichard, in the *Reports of the British Association for the Advancement of Science*, for 1847, p. 243. It is right to state that the substance of this section on language is borrowed from Dr. Prichard's Report.

principal means of determining their relation to each other, and the meaning intended to be conveyed.

The Syro-Arabian languages are a very ancient and important group, which appear to have been spoken from the very earliest times by the various nations inhabiting Asia to the westward of the Tigris. They also extended widely, and at a very early period, into Africa. The principal Asiatic idioms are the Chaldæan, the Hebrew, and the Arabic. Besides these are the Abyssinian dialects, the old Libyan dialects, and some others in Africa.

It appears probable from the present state of our knowledge, that only two races of people and two languages exist in the vast regions of Southern Africa. These are the Hottentots, in the most southern parts, and the great nation allied to the Kafirs of the eastern coast. They belong to one family, all their languages being dialects of one speech.

Central Negroland presents a multitude of languages or dialects which also have relations with each other sufficiently marked to induce us to regard them as being of one common origin.

The languages of the islanders of Polynesia are considered to offer resemblances, which cannot be the effect of casual intercourse, but are essential affinities deeply rooted in the construction.

In America, the northern extremity is peopled by the Esquimaux, whose language is known, and extends from Asia. Southwards, to a considerable distance, two great families of native languages are presented, one on the eastern, and the other on the western side; while still further southwards, and as far as Mexico, the Cherokees and other Indian tribes form a group with a distinct tongue. In Mexico are two principal and many less important languages, while South America contains a vast variety of different tribes, whose languages have been grouped into three, many of them, however, being very little known.

It may here be observed, that although languages, as intellectual creations of man, and closely entwined with his whole mental development, bear the stamp of national character, and as such are of the highest importance in the recognition of the similarity or diversity of race, they yet present many illusions to be guarded against, as well as a rich prize to be attained. Positive ethnological studies, supported by profound historical knowledge, teach us that a degree of caution is required in these investigations concerning nations and the languages spoken by them at particular epochs. Subjection to a foreign yoke, long association, the influence of a foreign religion, a mixture of races, even when comprising only a small number of the more powerful and more civilized immigrating race, have produced in both continents similarly recurring phenomena—namely, in one and the same race, two or more entirely different families of languages; and in nations differing widely in origin, idioms belonging to the same linguistic stock. Great Asiatic conquerors have been most powerfully instrumental in the production of striking phenomena of this nature.*

173 *Modification of the Races of Men.*—It is an important consideration that in many countries, where there has been no recent influx of different tribes, and where no cause of change is perceptible but the slow and gradual advance of civilization, and the progress of intellectual and moral development, there has yet been a very considerable modification of the physical characteristics of the prevailing races. It is desirable to consider how far this may have acted in past times with other portions of the great human family.

Civilization may, and in some cases does, produce two effects, as it not only occasionally modifies the existing race, but also drives before it and destroys less powerful, although indigenous tribes. Thus, if as seems probable, from the comparison of language, and from the occurrence of bones of men in places now covered up by deposits containing other human bones of great antiquity, there were originally Mongolic tribes over a great part or

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* Humboldt's *Cosmos*, Col. Sabine's translation, (1846,) vol. i. p. 354.

the whole of Europe, including the British Islands, and if, as it is equally certain in Western Europe, and in the British Isles, there are no present indications of the race either in structure or appearance, we must conclude that the advancing and conquering nation has destroyed the indigenous tribes, without permitting the blood of the two races to become mingled. Examples of physical change in a race during the progress of civilization are seen in Germany, where the accounts given of the physical characteristics of the inhabitants only a few centuries ago oblige us to believe that the prevailing colour of the hair was then yellow or red, and that of the eyes blue. Without any further admixture of blood from a dark-coloured race, this has now undergone much alteration, for the prevalent colour, not only in the large towns, where mixture of blood may have been the cause, but also throughout the country, is certainly very different. With regard to this subject we may also refer to the authority of Dr. Prichard, who says, in his work on the *Natural History of Man*, already quoted, 'I can assert from my own observation that the Germans are now in many parts of their country far from a light-haired race. I have seen a considerable number of persons assembled in a large room at Frankfort on the Maine, and observed, that except one or two Englishmen, there was not an individual amongst them who had not dark hair. The Chevalier Bunsen has assured me that he has often looked in vain for the auburn or golden locks and the light cærulean eyes of the old Germans, and never verified the picture given by the ancients of his countrymen till he visited Scandinavia; there he found himself surrounded by the Germans of Tacitus.'*

It appears indeed beyond question, that not only the Teutonic race, but even the Celtic have undergone much change in this respect, for there seem to be abundant traditions asserting the prevalence of yellow, and even white hair among the people of that race, anciently inhabiting Ireland, Scotland, and Wales. Now, it is certain that the present Highlanders are by no means a yellow or red haired people generally, although some districts present this characteristic. The prevalent characters in most part of the north of Scotland are dark brown lank hair, with a fair complexion and grey eyes. Since the mixtures that have been most common in all the western nations have consisted of Celtic and Teutonic blood in some form, we thus have no reason in this respect for the change of colour. It must be referred partly, perhaps, to a modification of climate effected by drainage and the removal of forests, partly to different food, and partly to the different condition in which men now live.

The influence of a race of men migrating into a new country will necessarily differ in some respects, according to the circumstances under which they appear and are received. Conquest and simple colonization may, for example, produce different results, but still it appears from the experience of past times, and even of very recent immigration, that the more civilized race will generally prevail, and not only so, but will gradually destroy the aborigines of the newly visited tract. The traces that are seen in various ways of the existence of a race of men in Europe before the present Indo-European race was introduced, are so slight, and have apparently produced so little physical change, that they must be almost neglected in any consideration of this kind, and thus the new race must be regarded as having quite driven out and destroyed the earlier one. When we find a few tribes still retaining their places and natural characteristics in some mountain fastnesses, as the Basques in the Pyrenees, we see more clearly the possibility of such extinction of races, and may recognise the circumstances under which it is possible.

Of all cases of incursion presented in history, those of the Hellenic race into Italy from the south, and subsequently of the Teutonic race from the

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* Prichard, *ante cit.*, p. 197.

north, and that of the Scandinavian branch of the same great family to Northern France and Britain, are the most remarkable and the most distinctly traceable. Others had occurred in earlier times in Asia, concerning which we know comparatively little that is definite, and a similar great experiment is now being tried in America, and also in Australia, New Zealand, and some of the other islands of the Pacific. In China, however, incursions have been made, the result of which is different, as there the conquering tribes, insufficient in number and inferior in cultivation, have only succeeded by superior physical energy, and have obtained the government without changing the people.

The lost races of antiquity naturally present many points of great interest, especially when from time to time their memory is recalled by the discovery of remains due to their labour or their ingenuity. Thus the Babylonians and Assyrians, the ancient and aboriginal tribes of Greece and the Etruscans, and the much later inhabitants of Lycia, nations which had attained to some degree of civilization, and amongst whom the arts of construction and sculpture were really and very successfully cultivated, have so far tended to modify succeeding and long subsequent generations of men, that we naturally inquire into the circumstances of their destruction. They appear before us as races of civilized men destroyed by barbarians; and although from these barbaric conquerors greater, more highly civilized, more intellectual, and more important nations have often arisen, still the first change was that of destruction effected by physical force against all the advantages of intellectual superiority. While, also, some of these nations—including several formerly inhabiting Asia Minor—were utterly destroyed and their cities buried in heaps of ruins, others, as the Jews, have survived, though as wanderers over the earth; while the Egyptians have retained their name and their place, although all the advance once made by them in civilization has relapsed into a monotonous and hopeless state of ignorance and slavery.

The events of the last two centuries have shown that the influence of civilized men determinately and permanently occupying a country may, as in North America, tend to the absolute extermination not only of tribes, but of many aboriginal races, and the day is perhaps not far distant when the so-called American Indians shall cease to exist, every effort having failed to induce them to adapt themselves to the circumstances forced upon them, and no real advance having been made in the modification of the race by the admixture of tribes or the introduction of civilization. Total extermination is manifestly a possible event with regard to a whole people, even where room is left for their existence, when they are encouraged to adapt themselves to new conditions, and when no check is put upon them beyond that degree of encroachment which would demand only a change of habit to render it harmless.*

174 *Mixture of Races.*—In various parts of the world circumstances have enforced a considerable mixture of the great natural families of men, and although there is some reason to believe that this mixture is not in itself natural, yet as it results in the production of such modified characteristics as may in the end form real groups, it becomes right to consider here some remarkable instances of the kind where the mixture of race has been complete, and where the two tribes combining are distinctly recognisable.

The extreme cases of mixture that can occur are, of course, those of different members of the three typical classes—namely, the Caucasian with the Negro or Mongolic, and the Mongol with the Negro. The mixtures of typical Caucasian, Negro, and Mongolic tribes with Americans and Malays are

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* There is, however, an apparent exception in the case of the Cherokee nation, who are described as settling in villages, and giving up their wandering habits for the arts of civilization. The Indian tribes in some parts of North America, and especially in Canada, seem also to have cultivated the land to some extent, as within the historic period an Indian town stood surrounded by corn fields on the site now occupied by the city of Montreal.

interesting in the next degree; and many cases of admixture of the early derived races, such as Celtic, Teutonic, and Sclavic; Hindoo, Arabic, and Egyptian; or mixed European with mixed Asiatic races of the same original stock, are scarcely less interesting or important in an ethnological view.

Dr. Prichard has put it forward as his decided conviction, that races of men, of whatever kind, are equally prolific, whether marriages be contracted between individuals of the same or of the most dissimilar varieties, and he adds, 'If there is any difference, it is probably in favour of the latter.'*

America is a country where mixtures of the Indo-European race of various families (Spaniards, Portuguese, English, German, Dutch, and French, and even Jewish,) have been effected, under tolerably equal and favourable circumstances, with the American Indians of various tribes, and with many tribes of Negroes from the centre and west of Africa; and it has been calculated by M. Rugendas, (*Voyage dans le Brezil*, Paris, 1835,) that out of a population of upwards of thirty millions in various parts where settlements have been made, the proportion of mixed races is as much as fifteen per cent., that of the various Negro tribes being eighteen, of native Indians twenty-seven, and of whites of all kinds forty per cent.

Since the mixture of races appears in some cases to have produced a really new and intermediate stock, it may be well to mention the instances of this kind before proceeding to the subject of mixed races where there is still a doubt as to the permanence of unity of character of the produce.

Among the instances of new tribes formed by the mixture of two well marked races, that of the Griquas, or Griqua Hottentots, is mentioned by Dr. Prichard, as having been the result of the intermarriages of the early Dutch colonists of South Africa with the aboriginal Hottentots, while the so-called Cafusos form another race derived from the mixture of the native Americans of Brazil with the Negroes imported from Africa. The former tribes are a powerful and marauding race, living on the borders of the colonial territory on the banks of the Gareep or Orange River, along a distance of seven hundred miles. Some of them are thriving agriculturists, and others are collected into a large community settled under Moravian missionaries.

The Cafusos exhibit very remarkable physical peculiarities. They are described by Spix and Martius (*Reise durch Brazilien*) as being slender and muscular—of a dark copper and copper-brown colour—having an oval countenance, with high cheek bones, but not so broad as the Indians; broad and flattened nose, neither turned up nor much bent; broad mouth, with thick but equal lips, which, as well as the lower jaw, project but little; black eyes, intermediate in position between that of the Indians and the Negroes, and excessively long hair, half curled at the end, and rising almost perpendicularly from the forehead to the height of a foot or a foot and a half.

Another remarkable mixed race is seen in New Guinea along the northern coast, and in some adjacent islands, obtained from the mixture of Negro with Malay blood. These 'Papuans,' as they have been called, have large bushy masses of half-woolly hair, measuring from two and a half to three feet in circumference, and the people have for this reason been called 'mop-headed.' Their skin is deep brown, the hair black, the nose broad, and the lips thick, and the shape of the skull approaches that of the Malays.

The mixtures of white with negro blood in America offer many peculiarities worthy of notice. The first issue of the European and African (called *mulatto*) is a medium in colour, figure, and even in moral qualities; the colour being yellow, brown, or tawney, according to the complexion of the father, (mulattos derived from the marriage of a black man with a white woman are comparatively rare,) the hair curled and black, the iris dark, and the race superior in cleanliness, capacity, activity, and courage, to the Negro. The successive addition of European blood is considered to restore all European

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* Prichard, *ante cit.*, p. 18.

qualities in the third generation, and the same number of generations is required to reduce the race to the original Negro. In the second stage, the *terceron*—the produce of Europeans and mulattos—the hair and features are European, and the former has no woolly curl, but the skin has a slight brown tint, although the cheeks are red. The next generation, the children of the European and the terceron (called the *quadroon*) are undistinguishable from whites.

An interesting variety is obtained by the mixture of European with native Indian blood in South America. The offspring in this case is called *mestizo*, and has the hair black and straight, the colour almost pure white, and the skin peculiarly transparent, the iris dark, the beard small, the extremities also small, and the eyes placed somewhat obliquely.

Among the various races of men, it is well worthy of notice, that the mixtures that most readily take place seem rather at the will of the lower than the higher race—the Negro woman willingly cohabiting with the white man at his pleasure, although the white woman rarely intermarries with the Negro man. It is also the case that the beardless or the woolly haired tribes acquire a Caucasian expression of beauty from a first intermixture, while very often both stature and form excel that of either type; and in another case, in the second generation, the eyes of the Mongols become horizontal, and the face oval. The crania also of the Negro stock immediately expand in their hybrid offspring, and the impression on subsequent generations is more durable than when the order is reversed.*

175 *Influence of Man on other Animals.*—There are perhaps many instances to be found in nature, where, owing to some local peculiarity of climate or vegetation, one race of animals multiplies to the injury or extermination of another, or is modified to adapt itself to altered circumstances It is only man, however, who is able to avail himself at will of the services of his fellow-creatures, and can induce them to change their place of habitation, their habits, and their natural tendencies, when such change conduces to his comfort or luxury. We must here consider a few of the cases where this modification is most decided, to understand fully the position of man in the scale of creation.

In establishing himself in a new country, the colonist will naturally endeavour to avail himself of the existing and indigenous animals, to introduce others most useful and necessary for his purposes, and to destroy those species from which he can expect no advantage, and which may injure the products he desires. In addition to this, and whilst introducing new animals and vegetables, he introduces also unwittingly others which depend on them for sustenance, and thus also tend to modify existing races.

The tribes of animals most useful to man, and which have been most generally domesticated, are, the dog and cat among carnivora; the ox, sheep, and goat among ruminants; the swine and horse among pachydermata; the rabbit amongst rodents. Each of these offers many facts showing the possibility of change in external form, and even internal structure, to a very remarkable degree, when exposed to the influence of civilization.

The dog as the companion of man in almost all countries has undergone changes so considerable, that it is now equally difficult to decide whether there was really but one original stock, or whether the numerous races are only fertile hybrids. Of all the dogs, that of Australia lives in the wildest and most natural state, and approaches in the structure of the skull most nearly to the wolf, exhibiting little sagacity, and being scarcely obedient to man. The Danish dog and mastiff come next in this respect, and are succeeded by the terrier and the hound, in whose skulls a larger cavity is left for the brain. The shepherd's dog has a very considerable capacity of cranium, and in the spaniel and water dog this capacity is still greater. These and the

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* Hamilton Smith, *ante cit.*, p. 131.

other varieties differ much in their stature and size, and in the shape of their ears and tails, which latter have from sixteen to twenty-one vertebræ, varying in particular breeds. Some tribes have an additional toe or claw to the hind foot, and some have additional or false molars. The hair also varies greatly in different breeds, being in some almost absent, and in others extremely developed, either as long silky or woolly hair; and, in short, the dog presents all the varieties of hairy covering of the body met with in the entire class of mammalia.

Now all these changes and modifications of the natural and original condition of the dog are due to his association with and employment by man. He accompanies his master to all countries, hunts with and defends him in every climate and under all circumstances, never recurring to the wild state, or evincing any desire to recover his liberty. It is difficult to know which to admire most, the pliancy and adaptability of the servant, or the pertinacity with which the whole race clings to the intellectual and moral superiority of the master.

The ox and the sheep offer difficulties scarcely less considerable, and present varieties almost as marked as the dog. Whatever we regard as the source of domestic cattle, and whether they are of one or more original wild varieties, it is certain that they have undergone by domestication such changes in form, dimensions, structure, hair, horns, tail, and other important characteristics, that they are no longer to be traced back without the greatest difficulty. The breed of cattle introduced by the early settlers in South America has, however, succeeded in covering that part of the western continent, and is fast destroying many indigenous races. The sheep, also—one of the most anciently domesticated animals—is one in which very great varieties are displayed; and here it is probable that several species have become mixed, and that many of the breeds are fertile hybrids. Some when transported to foreign countries retain their peculiarities more distinctly than others, but all seem to undergo great change after a few generations, approximating to the local peculiarities of form and structure. In this animal, new breeds have been produced occasionally, by taking advantage of individual peculiarities and deformities, and no doubt the numerous varieties presented are all greatly influenced by human agency.

The horse is found wild in some parts of Asia and Africa, but it is very doubtful whether in either case we see the original species, and not a cultivated race escaped from civilization; and varieties of size, shape, and colour are so marked, that all resemblance is lost by which we can decide the question of original identity. The swine, if not so greatly varied, exhibits proof of change equally satisfactory, some breeds having solid hoofs, others very long ears couched upon the back, others a large pendant belly, and very short legs, while another, found at Cape Verd and other places, has large tusks, crooked like the horns of oxen.

On the whole, it undoubtedly appears that 'domestication effects a much greater change on the manner of existence than any removal from one country to another that can be imagined to take place during the continuance of the wild state. Its results are, in fact, more extensive on the nature of animals, for domestication is not a casual and temporary change effected in an individual, but the modification of a race, by which it becomes fitted to exist under new circumstances.'

The phenomena of variation thus offered, may be grouped under three heads, involving—first, differences of organic structure; secondly, physiological, and, thirdly, psychological differences.

The differences of organic structure depend at first either on an accidental variety propagated intentionally, and transmissible because of the tendency that exists throughout all nature to reproduce in the offspring the peculiarities of his immediate ancestor, or else of some modification directly produced by change of climate, better and more regular food, and more uniform shelter. External characters of many kinds connected with the skin, hair, &c., are easily modified in this way, and even the shape of the head and pelvis, the proportions of the extremities, length of neck, and other points of structure, admit of great variety.

Physiological varieties or diversities in the internal constitution are so frequently met with in individuals, that we can easily conceive differences to exist in races long detached from the parent stock, and subjected to the influence of man. The average duration of life, the number of the young produced at a birth, the period of gestation, the changes of constitution during life, these are points which may be regarded as specific; but even these yield, though to a smaller extent, to the effects of civilization and domestication. This is illustrated by the fact, that the cows of South America and those of Europe differ in the time of giving milk.

The habits and instincts of animals present, in the case of every species, a distinct psychological character, which has been less studied in its general natural-history value than as a subject of amusement and curiosity. These habits and instincts are, however, capable of modification in an extraordinary degree by association with man, and it is well worthy of notice, that instinct, to whatever degree it is cultivated in a race, is immediately and almost perfectly transmitted to the offspring, which accordingly will hardly require teaching to perform the same tasks. That this is the case in dogs, especially sporting dogs, has been long known; but it is also the same with other animals, as we are told 'the hereditary propensities of the offspring of the Norwegian poneys, whether full or half-bred, are very singular. Their ancestors have been in the habit of obeying the voice of their riders, and not the bridle, and horse-breakers complain that it is impossible to produce this last habit in young colts; they are, notwithstanding, exceedingly docile and obedient when they understand the commands of their master. It is equally difficult to keep them within hedges, owing perhaps to the unrestrained liberty the race may have been accustomed to in Norway.'*

On the whole, then, it is clear that man has by domestication, and especially as he has himself advanced in civilization, very much changed and modified many tribes of animals, removing them into distant countries, inducing them to accustom themselves to different climates, and training them to habits and instincts altogether new and peculiar; thus encouraging remarkable modifications in form, colour, integument, internal structure, and other points of animal economy, and, at length, permanently fixing numerous varieties, often more widely separated than the original type from nearly allied but very distinct species.

176 *Influence of Man on Inorganic Nature, and on the Vegetable Kingdom.*—Wherever man plants himself, and advances beyond the mere animal condition, by the exercise of his intellectual faculties—wherever, in a word, there is found any trace of *civilized man*, there we shall also find that external nature has undergone some change. Thus, when immigration takes place to a country covered thickly with virgin forests, which have continued in the same state for hundreds or even thousands of years, the forests are soon cut down, and are replaced by fields of waving corn. So where Nature has left wide stagnant pools, extensive barren tracts, or plains covered with plants useless to man, all these things are readily changed by his active exertions, and soon, in consequence of these alterations in condition, the climate also becomes modified; this again, as we have already seen in the case of Germany and elsewhere, reacting upon the physical characteristics of the inhabitants of the district.

In a former chapter, when speaking of the natural limits of distribution of certain vegetable and animal species, and the representative forms met with under similar conditions of climate in distant countries, some reference was made to the power of man in this respect, and his habit of introducing by

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* Mr. Knight, quoted in Prichard, *ante cit.*, p. 72.

art many plants and animals into climates altogether new to them. This, we have also had occasion to consider, as far as animals are concerned, in the present chapter, and now it is only necessary to recal a few striking facts, which will illustrate the same general law in the case of plants and climate.

It is impossible even to imagine the original food of the human race, but we certainly know that the Banana and the Plantain must have been in use from a very early period, since neither of them, from the oldest times of which we have record, appeared in the state of nature, but only as essentially altered by cultivation. Very early, too, must men have made the large-seeded Grasses tributaries to his storehouse, for we know not the time when any of the plants now used as Bread-corn were transplanted from their native soil and rendered more useful to man.

'A striking phenomenon, which indicates the enormous antiquity of the culture of the *Cerealia* is that, in spite of many most profound investigations, we have not yet succeeded in discovering the proper native country of the most important kinds of Corn. Not one of the industriously inquiring travellers in America has ever met there with Maize otherwise than cultivated, or as evidently an outcast from culture. With regard to our European kinds of Corn, we have only very inaccurate indications that they have been found wild, here and there, in the south-western countries of Central Asia. But history proves that those regions formerly supported so large a population, and that there existed so high a condition of culture, that the assumption can scarcely be justified that those Corn-plants now found there are anything but descendants from plants which have escaped from cultivation.* From our knowledge of the great eastern portion of Asia, we are aware that in China a dense population can, by a certain degree of industrial culture, succeed in extirpating every wild plant, and in clothing the land exclusively with vegetables intentionally raised. Except some few water-plants in the purposely flooded rice-fields, the botanist finds scarcely any plant in the Chinese plains which is not an object of cultivation. Thus, it may not be at all impossible that the Cerealia—perhaps originally (as is the case now with so many Australian plants) confined to a narrow region of distribution, which was taken possession of at an early period by a strongly developing population —have actually wholly disappeared from our Earth in the character of original wild plants.'†

Other most important and beneficial changes have been produced by human agency in the case of various fruit trees (*e.g.* Apple, Pear, and Cherry), and in the common table vegetables of temperate climates. Who, for example, could recognise the Cauliflower, Savoy, and other Cabbages in the dry, nauseous, and bitter-flavoured Colewort—the undoubted stock of these vegetables; or who, comparing the cultivated with the wild Carrot, could believe that the one was derived from the other. In all these cases, by actual cultivation, man is able to modify particular plants, and render even those which are apparently injurious useful articles of universal and grateful food.

But much more than this is done—for the work is done on a far larger scale—by those processes of clearing and preparing for human habitation to which we have already alluded. Nor are these processes always successful in permanently improving the district subjected to their influence; for we find in ancient human records, or in those handed down by Nature herself, sufficient proof that parts of Egypt, Syria, Persia, &c., now burnt up by the sun, arid from want of water, and allowing only a very sparing population, were once clothed with vegetation, well watered by considerable streams, and capable of feeding as many thousands as there are now hundreds.

In contrast we may take the case of the Rhine and the country on its

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* Wheat grown from seed obtained from Egyptian mummy cases of great antiquity has, within the last few years, been cultivated in England. It appears to have some peculiar and distinctive characters.

† Schleiden's *Plant*, translated by Henfrey for the Ray Society, p. 297.

banks, where is now raised one of the finest of European wines, but where in the time of Tacitus not even the cherry, much less the grape, would ripen. The disappearance of the forests commenced and originated the mighty change. So also, in other cases,the cultivation of clover, requiring a moist atmosphere, has passed from Greece to Italy, thence to Germany, and is now flying still further towards the Western Ocean. In Egypt, Pythagoras forbad his scholars to live upon beans; but no beans grow there now to feed them. The wine of Mareotis, celebrated by Horace, and capable of inspiring the guests of Cleopatra, grows there now no longer. The pastures at the foot of the richly watered Ida—Argos, once celebrated for its breed of horses—the Xanthus, with its hurrying waves—these are all histories of the past; they are reminiscences of what man has done, but they are now no longer possible.

We may conclude this view of the result of human cultivation in the words of Schleiden adapted from those of Elias Fries.*

'A broad band of waste land follows gradually in the steps of cultivation. If it expands, its centre and cradle dies, and on the outer borders only do we find green shoots But it is not impossible, only difficult, for man, without renouncing the advantage of culture itself, one day to make reparation for the injury which he has inflicted; he is appointed Lord of Creation. True it is that thorns and thistles, ill-favoured and poisonous plants, well named by botanists *rubbish plants*, mark the track which man has proudly traversed through the Earth. Before him lay original nature in her wild but sublime beauty; behind him he leaves the desert, a deformed and ruined land; for childish desire of destruction, or thoughtless squandering of vegetable treasures, have destroyed the character of nature, and man himself flies terrified from the arena of his actions, leaving the impoverished Earth to barbarous races or to animals, so long as yet another spot in virgin beauty smiles before him. Thus did cultivation, driven out, leave the East, and perhaps the deserts, formerly robbed of their coverings; thus, like the wild hordes of old over beautiful Greece, this conquest is now rolling with fearful rapidity through America, the eastern countries becoming barren through the demolition of the forests only to introduce a similar revolution into the far west.'

177 *Effect of Inorganic Nature on Man.*—We have seen that whatever effect is produced by human agency on the animal and vegetable world, reacts on the human race in its turn, and thus at length modifies its physical characteristics. But the civilization of any great natural family of men is an event which depends on something more than accident, and which is doubtless very much influenced by the circumstances of external nature, so that it becomes necessary to consider how far we can fairly refer many differences that we see to such external influence as climate, fertility, and geographical position.

With regard to all these points, it seems certain that man, although perfectly capable of settling and becoming the permanent inhabitant of almost any part of the Earth, yet has not the higher qualities and powers of his nature developed except in temperate latitudes; where his time is neither entirely and necessarily divided between the search for coarse animal food and the repose and torpidity induced by extreme cold, nor, on the other hand, entirely at his own disposal, in consequence of the abundance of fruits presented by a too bountiful Nature and always ready at hand when he desires food. The former is the case with the Esquimaux and other tribes of Northern Asia and America, and the latter occurs in those warm islands and shores (of which there are many) where the labour of a day will supply a week's food, not only for an individual but for the family dependent on him, and where the lassitude arising from heat encourages almost total idleness. The north temperate zone has from the commencement of civilization been the cradle of all those races which have had force and energy to conquer, talents to govern, and ingenuity to advance in the mechanical and fine arts.

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* Schleiden's *Plant, ante cit.*, p. 306.

Difficulties have always tended rather to excite the powers than to check the efforts of man; and, therefore, in the end, those who have had most to do in their contest with Nature have not only done the most, but have taken absolutely the highest place, and produced the greatest effect upon their fellow-men. At all times, the Chinese have exhibited a certain amount of civilization, and in ancient times the Egyptians, the Babylonians, the Assyrians, and the Chaldees, and the Hindoos in the eastern division of the great Indo-European world—more recently the Greeks, and after them the Romans—and in modern times, the inhabitants of countries still further west have taken the lead, and have carried the arts and sciences to gradually increasing perfection; but it is important to remember that this has been done in proportion as the climate of these countries has undergone change, and that the improved civilization of the western races has been accompanied, if not assisted, by a gradual equalization and amelioration of the temperature, the winter becoming less severe, and the summer longer and more available, even if the absolute amount of heat distributed in the year has undergone no considerable alteration. Thus each of the three great natural families of man inhabiting the temperate zone, have always presented some people of principal civilization, but those tribes dwelling in tropical countries have not advanced far, and many of them have never emerged from the darkness of absolute barbarism. And while we find the advancing nations of the western hemisphere always exhibiting their highest qualities where a necessity for exertion was evident without a satisfactory result being hopeless, the nations of America before the discovery of that continent by the Europeans had also attained a certain though small amount of civilization, presenting in some respects a parallel to the Assyrians and Egyptians, but not tending, it would seem, to any further or more useful advance, and thus to be compared with the Chinese rather than the Indo-European race.

Although an important relation certainly exists between the state and condition of nations and the circumstances of their physical geography, the opinion of M. Victor Cousin can by no means be entertained—namely, that if any country be examined in reference to the latter, it will be possible to tell *à priori* what is the condition of men in that country, and what part its inhabitants will act in history. The exceptions to this rule are important, for they occur in those cases where a mixture of blood or the immigration of a different stock has changed the tendencies of the inhabitants. The objects first to be obtained in a new settlement are food, needful raiment, and sufficient shelter from the inclemency of the weather. If these are either too easy or too difficult of attainment, the development of the race, so far as the exercise of the higher powers of human nature are concerned, is checked and prevented; but if these require moderate exertion and call for ingenuity, and if, moreover, the race is one of those in which intellectual advance is the rule, and not the exception, then may we expect that the very struggling to overcome difficulties will give fresh power and energy, and induce the exercise of the various useful arts and sciences.

178 *Statistics of the Human Race.*—There are some numerical and tabular facts regarding the human race in its various natural divisions, that seem worthy of notice in this place, as bearing upon the general subject before us. Thus, the estimated population of the globe, the way in which it is believed that population is distributed, the rate of increase, the limits of increase, the relative physical development of various races, the duration of life, and other similar matters, possess much interest, and assist us in obtaining accurate notions with regard to the human race.

According to Balbi, the actual present population of the globe is about 737 millions, distributed as follows:—

Europe, with its adjacent islands	227,700,000
Asia, ditto	390,000,000
Africa, ditto	60,000,000
America, (North and South,) ditto	39,000,000
Australasia, and other islands of the Pacific	20,300,000

The number of square miles of land on the Earth is estimated as about 51½ millions, and, therefore, we have, on an average, about fourteen and a third persons to a square mile. To give an idea of the amount of increase conceivable, we may state that in China it has been estimated that more than a hundred persons, on an average, are planted on each square mile of that vast empire, although very large tracts are hopelessly barren; while, as the population of England and Wales at the last census was about fifteen millions, and the countries together contain about 50,000 square miles, there are seen to be with us not less than 300 on an average to each square mile. Of the whole population, however, one-third reside in large towns (of 10,000 and upwards).

The rate of increase of mankind it is not easy to calculate, except in very limited districts. In the thickly peopled districts of England, the increase in ten years, ending 1841, amounted in towns to 20·2 per cent.; in the rural districts to 11·2 per cent.; and in the whole population together to 14·4 per cent. The annual increase may, perhaps, be fairly estimated as being now about one and one-third per cent.

Of the whole population of the world, it is thought that about one thirty-third part (three per cent.) die every year, and that the stock is during the same interval increased by somewhat more than a thirtieth (three and a third per cent). This would give about 23¾ millions born, and 21¼ millions dying in each year. Although, however, the average mortality is reckoned so high, the mean average of life in the human race is much more than thirty years, and in spite of the large number of children and young persons who meet with an early grave, (one-fourth of the infants born dying before they are a year old, while half the whole number do not attain the age of twenty-two years,) the mean duration of life must be considered to amount to from thirty-eight to forty-two years, according to circumstances.

The number of male children born in civilized countries exceeds that of females by about one-twentieth part, but in consequence of greater exposure to accidents, the destruction of life by war, and unhealthy employments, the mortality of males is greater, and finally the women are more numerous than men. In Great Britain, at the last census, there was an excess of female population to the extent of 240,181, (being in the proportion of thirty-nine to thirty-eight nearly,) although there was during that period an annual excess of male births in the proportion of twenty to nineteen.

The average number of children to a marriage in Europe varies in different countries, from three and a half to nearly five and three-quarters, being least in Northern Europe and greatest in Savoy. It may be considered that the ordinary proportion in England is four births to each marriage. Perhaps one cause of the proportion being comparatively small in England is, that from prudential and other motives, marriages frequently do not take place till somewhat later in life than in many other countries in Europe; but another and more important one arises from the fact that so large a proportion of the inhabitants dwell in large towns.

The general proportion between births and deaths taken one year with another, and for a large extent of the civilized world, may be considered to vary between 100 and 150 births for every 100 deaths. It is probable that a larger proportion than the latter can hardly exist under the most favourable circumstances, while the former can only take place where there are some causes of unusual and even fearful mortality.

The true proportion between births and deaths for a number of years cannot at present be determined with certainty, owing to a want of accuracy in the registrations. In England, however, it is probably as 150 to 100.

With reference to the original peopling of the Earth itself, or of new countries, it has been calculated that under very favourable circumstances the human race may be tripled in about twenty-four years. It has, also, been supposed that the posterity of one male and female might in three hundred years, if not interfered with, amount to a population of about 4,000,000 of souls.

The ordinary mortality of a country with reference to its whole population varies, of course, according to the climate and mode of life of the people. In England (including Wales), it is estimated to amount to about one forty-sixth, that proportion of the whole population dying annually. In France, it is estimated at one-fortieth, and in Russia the same; while in some selected spots, as, for example, in North Wales and part of Surrey, it reaches to only one fifty-fifth.

In England, at the last census, the ages of nearly 16,000,000 of individuals were returned, thus giving very interesting facts with reference to the duration of human life. We quote this table as given in Macculloch's *Statistics of the British Empire,* (vol. i. p. 424):—

AGES.	Population calculated for July 1, 1841.			Deaths registered in 1841.			Annual mortality per cent.			One death to so many persons living of each year as are in this table.
	Persons.	Males.	Females.	Persons.	Males.	Females	Mean.	Males.	Females	
0—1	429,419	210,507	218,912	74,210	41,444	32,766	17·355	19·726	14·984	6
1—2	429,803	215,493	214,310	27,268	13,987	13,281	6·353	6·503	6·204	16
2—3	437,276	218,208	219,068	15,027	7,516	7,511	3·441	3·451	3·432	29
3—4	410,077	203,653	206,424	9,914	5,028	4,886	2·422	2·474	2·370	41
4—5	401,555	201,238	200,317	7,164	3,620	3,544	1·786	1·802	1·771	60
0—5	2,108,130	1,049,099	1,059,031	133,583	71,595	61,988	6·349	6·833	5·860	16
5—10	1,906,576	953,893	952,683	17,868	9,093	8,775	·938	·955	·922	107
10—15	1,733,652	881,129	852,523	9,116	4,478	4,638	·527	·509	·545	190
15—20	1,588,340	782,425	805,915	12,056	5,604	6,452	·759	·718	·801	132
20—25	1,551,703	724,013	827,690	13,922	6,633	7,289	·900	·918	·882	111
25—30	1,284,020	611,390	672,630	12,889	6,045	6,844	1·005	·991	1·019	100
30—35	1,167,954	565,226	602,728	11,414	5,422	5,992	·978	·961	·995	102
35—40	885,306	435,430	449,876	11,195	5,385	5,810	1·266	1·239	1·293	79
40—45	888,806	435,991	452,815	10,510	5,251	5,259	1·185	1·207	1·163	84
45—50	639,202	313,709	325,493	10,244	5,322	4,922	1·607	1·700	1·514	62
50—55	634,940	307,435	327,469	10,811	5,673	5,138	1·710	1·849	1·571	58
55—60	392,166	189,816	202,350	10,552	5,418	5,134	2·700	2·860	2·540	37
60—65	440,110	209,248	230,862	13,813	7,090	6,723	3·155	3·395	2·915	32
65—70	259,839	120,829	139,010	14,071	6,881	7,190	5·442	5·706	5·178	18
70—75	224,431	104,138	120,293	15,569	7,630	7,939	6·974	7·341	6·607	14
75—80	120,015	55,653	64,362	14,525	6,992	7,533	12·152	12·586	11·717	8
80—85	70,494	31,136	39,358	11,681	5,358	6,323	16·662	17·242	16·083	6
85—90	24,008	10,149	13,859	6,550	2,841	3,709	27·418	28·047	26·790	4
90—95	6,541	2,493	4,048	2,243	898	1,345	34·677	36·091	33·264	3
95—100	1,421	497	924	604	220	384	42·972	44·352	41·592	2
100 and upwards	249	82	167	110	29	81	41·829	35·221	48·438	2
All ages	15,927,867	7,783,781	8,144,086	343,847	174,198	169,649	2·160	2·238	2·083	46

In this table the whole population of England is included, and the last column shows the mean mortality at any given age. Thus, between the ages of fifteen and twenty, one person out of every one hundred and thirty-two dies per annum. The annual mortality column, read without regarding the decimal points, expresses also the number who die each year of any age out of every hundred thousand.

The mean age of the male population of England, taken from this table, would be twenty-five and a half years, the young predominating, owing to the increase in the population, and the higher average of deaths in the earlier periods. If the community were stationary, the mean age of the people would be (*cæteris paribus*) thirty-two years, and the mean age of death a little more than forty-one years.

We have given these latter statistical details chiefly from our own country, because the information is, we believe, at least as full and accurate, and the general result as satisfactory, as is the case with any others that have been published. In many respects, too, they contain positive data not elsewhere to be obtained, but it is right to add that the Belgian statistics are also most carefully and minutely tabulated.

General Conclusion.

We have now reached the close of our work on this great subject of Physical Geography, and it might, perhaps, be thought advisable to revert to the main facts placed before the reader, or consider the general harmony of the subject and the mutual bearing of every part on the whole. But, in fact, it would be difficult to collect into a few pages the results of the numerous facts already presented in a condensed form, and it is better to give a simple outline of the advantage that ought to be derived by the student than endeavour merely to impress upon him the extent or the difficulty of the task. If we look back to the middle ages and notice the rarity of general information and the difficulty of obtaining it, we may perceive some excuse for the practical as well as intellectual ignorance of the multitude of that day. They could and did observe isolated facts, of whatever kind, even as we do now, and the phenomena of nature did not, we may be sure, then pass unnoticed by the shrewd and thinking men who were in a position to observe them. But there were no means readily at hand of spreading and comparing information, and thus, before the invention of printing, facts were almost useless, because they were isolated, and could not conveniently be worked into that form in which they become materials for generalization. The discovery of printing gave a facility for this, and then 'the sparks of information, from time to time struck out, instead of glimmering for a moment and dying away in oblivion, began to accumulate into a genial glow, and the flame was at length kindled which was speedily to acquire the strength and rapid spread of a conflagration.' But although this outbreak of science, and its sudden and vast expansion, and steady, unremitting progress up to the present time have indeed been marvellous, it is manifest that there is still much room for further increase when the people of each country shall be sufficiently well informed on every subject to bring their powers of observation into useful bearing, and occupy their leisure with distinct investigations of Nature and her works. It is the accumulation of knowledge by the people individually, that must be looked to as the source of great future discoveries, and such knowledge as that presented in the present volume is chiefly valuable as it gives useful, correct, and practical information to those who wish to learn and are willing to be useful. To quote again from the beautiful essay by Sir John Herschel, (already referred to above,) 'It is obvious that all the information that can possibly be procured and reported by the most enlightened and active travellers must fall infinitely short of what is to be obtained by individuals actually resident upon the spot.

Travellers, indeed, may make collections, may snatch a few hasty observations, may note, for instance, the distribution of geological formations in a few detached points, and now and then witness remarkable local phenomena; but the resident alone can make continued series of regular observations, such as the scientific determination of climates, tides, magnetic variations, and innumerable other objects of that kind required; can alone mark all the details of geological structure, and refer each stratum, by a careful and long-continued observation of its fossil contents, to its true epoch; can alone note the habits of the animals of his country and the limits of its vegetation, or obtain a satisfactory knowledge of its mineral contents, with a thousand other particulars essential to that complete acquaintance with our globe, as a whole, which is beginning to be understood by the extensive designation of Physical Geography; besides, which ought not to be omitted, multiplied opportunities of observing and recording those extraordinary phenomena of Nature which offer an intense interest from the rarity of their occurrence, as well as the instruction they are calculated to afford. To what, then, may we not look forward, when a spirit of scientific inquiry shall have spread through those vast regions in which the process of civilization, its sure precursor, is actually commenced and in active progress? And what may we not expect from the exertions of powerful minds called into action under circumstances totally different from any which have yet existed in the world, and over an extent of territory far surpassing that which has hitherto produced the whole harvest of human intellect? In proportion as the number of those who are engaged on each department of physical inquiry increases, and the geographical extent over which they are spread is enlarged, a proportionately increased facility of communication and interchange of knowledge becomes essential to the prosecution of their researches with full advantage. Not only is this desirable to prevent a number of individuals from making the same discoveries at the same moment, which (besides the waste of valuable time) has always been a fertile source of jealousies and misunderstandings, by which great evils have been entailed on science, but because methods of observation are continually undergoing new improvements, or acquiring new facilities, a knowledge of which it is for the general interest of science should be diffused as widely and as rapidly as possible. By this means, too, a sense of common interest, of mutual assistance, and a feeling of sympathy in a common pursuit, are generated, which proves a powerful stimulus to exertion; and, on the other hand, means are thereby afforded of detecting and pointing out mistakes before it is too late for their rectification.'*

It has been the object of the author to prepare a treatise which shall be useful in the way thus alluded to, and since 'one of the means by which an advanced state of physical science contributes greatly to accelerate and secure its further progress is the exact knowledge of physical data,' and that these data can only be known and made use of to advantage by the help of general knowledge of natural as well as mathematical science, he trusts that his portion of the present work is adapted to advance science in the right direction.

Herschel's *Preliminary Discourse*, p. 349.

THEORY OF DESCRIPTION

AND

GEOGRAPHICAL TERMINOLOGY.

CHAPTER I.

§ 1. Nature and divisions of the subject. — 2. Of positive position. — 3. Of relative position.— 4. Of land and water in extent. — 5. Of land in elevation. — 6. Of water not in motion. — 7. Of water in motion. — 8. Of the natural productions of the surface of the earth.

NATURE and Divisions of the Subject.—Descriptive Geography has for its object to give the knowledge of the superficial character of the Earth's surface, and its productions, whether vegetable or animal. It is, however, impossible to confine it strictly to these things, inasmuch as no description of either its vegetable or animal productions would be satisfactory if it were not accompanied by the knowledge of the things on which they depend, as soil, climate, &c., which belong to the department of Physical Geography, and more especially of man, for whom the present state of the globe was designed, and those works of his by which it is covered. But this involves some historical considerations; for it must be evident that in the same place may be found the results both of man's present and past labours. The fisherman's hut stands on the ruins of Tyre, the black tent of the Arab on those of Nineveh, vegetables transplanted formerly may appear indigenous now, and therefore the description of any country must vary much, according to the time with reference to which it is given. Descriptive Geography is, however, more immediately concerned with the greater and more abiding features of the surface of the Earth; the division of the Earth into kingdoms and states, with its results, belongs rather to Political Geography; the changes effected by man's residence in particular places, to Topography; but the latter involves itself with the former so intimately that it cannot be separated from it, for the knowledge of places (*τοπος*, a place) includes both their natural character, and the effect of man's residence in them; the first coming under the head of Descriptive Geography, and the second under Political; but as Topography descends to minor details and measurements, which have no direct or at least apparent effect on the world at large with which Geography proper concerns itself, and as the limits of the present work preclude minute details altogether, the description of the surface of the Earth may more profitably be considered in it under two leading divisions:—

1. The Earth's surface and natural productions.
2. The Earth's surface as affected by the residence of man upon it.

The first, it will be observed, is but an extension of what has been already treated of in Physical Geography; the mode in which it is to be treated must, however, be different. Science, it is true, is one and indivisible, but it is presented to our minds under different phases and in various connexions, and the unity is preserved, if the principles on which it depends are not violated, even if it be viewed from another aspect.

To describe any given part of the Earth's surface, three preliminary considerations are required:—1. Position. 2. Extent, or horizontal contour. 3. Form, or vertical contour.

Position is both positive and relative. The first is determined by Mathematical Geography; the second is the result of extent and form, as has already been shown in Physical Geography. Extent is dependent on form; but inasmuch as we are accustomed to obtain our knowledge of the Earth's surface from artificial globes, maps, and charts, and that which is first apparent on them after the position, is the extent of the countries depicted, it is better in description to preserve the order in which they are given above.

2 *Of Positive Position.*—If the globe of the Earth were a perfect sphere, and did not revolve in one uniform direction, arbitrary means could alone be resorted to, to determine the position of places; but being an oblate spheriod, having its shortest diameter for its axis of revolution, two points and one circle are at once determinable on its surface. The points called the Poles, at the north and south extremities of that axis, are so named with respect to their relative position to a certain point in the heavens, to which the mariner's compass, by the magnetic power imparted to it, is directed. (See *M. G.*, p. 6; and *P. G.*, p. 196.) In strict accuracy, a circle drawn round the Earth equidistant from those points, has its circumference greater than any other which can be described on the globe. (See *Chartography*, p. 179.) This circle, thus distinguished both in character and position, is called the Equator; by it the globe is divided into two equal parts or hemispheres, and another element for the right estimation of the position of any place obtained. In practice, however, the difference between this circle and any other drawn through two equidistant points on the globe, (having a longer diameter between them,) is inappreciable. As every circle is divided into 360 degrees, circles drawn through the poles, dividing the equator into that number of parts, or, if the scale admit, subdividing these again into minutes or other equal parts, will form limits by which the position of places may be ascertained; but as in a lateral direction—i. e. in the line of the equator—there are no fixed points like the poles, an arbitrary distinction between these circles has been necessitated, and this every nation has naturally made for itself, each reckoning these circles from some point apparently most desirable from local or political connexion. (See *Chartography*, p. 181.) We, in England, reckon from Greenwich, because the National Observatory is there; and these circles, called Meridians of Longitude, numbered from thence, enable us to ascertain the distance of any place from the meridian of that place in degrees; but as circles drawn through the same point approach each other, as they approach that point, so although the same number of degrees are estimated between each meridian, the length of a degree becomes less and less in proportion to its nearness to the poles. It becomes, therefore, necessary to limit the number of these circles, or the upper part of globes and maps would soon become confused by them; small divisions of lateral space must, on this account, be ascertained on a globe by the use of the brazen meridian and horizon, or by a graduated scale, or on a map by measurement. Degrees are thus estimated by inspection, but they may be reduced to miles by the rules already laid down (see *M. G.*, p. 72), or by reference to a table (see *Appendix* A), it being remembered that a degree at the equator is sixty geographical miles in length.

The meridians of longitude, or circles drawn through the poles, are of the same circumference*—viz., 360 degrees, of sixty miles to a degree, they are commonly called great circles; but, as those circles only can be great circles which are drawn through two points equidistant from each other, circles drawn, dividing them into equal parts, and consequently parallel to the equator, must be of less circumference, and gradually decrease as they recede from it: such circles are called Parallels of Latitude—parallel, because parallel to the equator, and of latitude now with justice, because they are on each side of it. The name, however, was adopted by the ancients when it was supposed that the extent of the Earth from east to west (its therefore so called longitude,)

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* On the comparative magnitudes of small and great circles. (See *M. G.*, p. 24.)

was greater than that from north to south, therefore called its latitude. The latitude and longitude of any place—i. e. its position on the surface of the Earth—is ascertained by observing what meridian and parallel cut each other, or what minuter divisions intersect, where it is situated.

The position of the Earth with respect to the Sun, its annual and diurnal rotations, afford additional means of estimating position. The apparent path of the Sun on the surface of the Earth is indicated by a great circle cutting the equator diagonally, called the Ecliptic (see *M. G.*, p. 14); the two points equidistant from each other where the two circles intersect are called the Equinoctial points (see *M. G.*, p. 56), and these for certain periods afford points from which to measure distance in its relation to time and the seasons. The extreme distances north and south of the equator to which the ecliptic reaches, mark the extreme points at which the Sun is ever vertical; these are termed Solstitial: and the zone or belt thus formed round the Earth limited by circles corresponding to the 23½° of latitude, and called respectively the Tropic of Cancer and the Tropic of Capricorn, from the signs of the Zodiac farthest from the equinoctial points, is called the Torrid Zone, and any place lying within it is said to be within the tropics. Beyond this, as far north and south as the 66½° of latitude, the Temperate Zone extends, and from thence to the Poles, 23½°, the Arctic and Antarctic respectively.

In Physical Geography, as has been noted, other zones, having reference to temperature, climate, natural productions, &c., are recognised, and all these may be applied to the estimation of the position, but rather relative than the positive, of places on the surface of the Earth.

3 *Of Relative Position.*—As all estimation of position in longitude must be to a certain extent arbitrary, east and west are only relative terms, and although position, north or south, is capable of more exact definition, yet when applied to the position of places with respect to each other, they likewise become relative. A place near the South Pole may be north of another still nearer that point—may be north of one and south of another place, or east, or west, or *vice versâ*. This is relative position on the globe. Having determined the position of the great continental masses, we may, in describing any place consider—1. What position it occupies in them, and in which of its great natural divisions it is to be found; 2. To what physical division or district it belongs; 3. How it is affected by political divisions; 4. Its position with respect to commerce. Each of these may be again re-considered in a general or particular relation, in a topographical or restricted, or a geographical or more enlarged sense; and although our object is to avoid topographical details as much as possible, the description even of countries, whether considered in their physical or political relations, would be very incomplete were not both attended to.

Relative position may not only be considered in extent, but in elevation; the point of departure for calculation is, by common consent, assumed at the sea level; and it may be estimated not only in actual height in miles, yards, or feet, but in regions of temperature also, as already noticed, the temperature decreasing with the elevation. (See *P. G.*, p. 325.) As, however, this varies, not only with the elevation, but in proportion as it recedes north or south from the influence of the Sun's rays, position thus estimated is more especially relative. Vertical position may be reckoned not only above but below the level of the sea; some, but comparatively few, places on the Earth's surface being thus distinguished.

From the considerations already entered into in the part on Physical Geography, it is apparent that the horizontal contour of the land depends on the sea by which it is bounded, while that again is the result simply of depressions in the land; and thus the form or vertical contour of the Earth's surface is the origin of all its superficial divisions; it is also that which is most apparent to the eye of man; but, on the other hand, the elevations and depressions on the Earth's surface are, when compared with its extent, entirely insignificant.

4 *Of Land and Water in Extent.*—The principal divisions of the land are called Continents, those of the water, Oceans. Of the former, it was customary to reckon four, Europe, Asia, Africa, and America; to these some added a fifth, Australia. Having regard, however, to the meaning of the word, and guided by the practice of modern geographers, the definition already given (see *P. G.*, p. 216) has been adopted—Continent, that which is connected together and continuous. There are therefore only two continents, the Old and the New—the former containing Europe, Asia, and Africa; the latter, America, North and South; to these the terms east and west have been respectively applied. They are, of course, only relative. The oceans divide the continents from each other.

Ocean is a word adopted from the Greek, and, from the use of its cognates in languages of similar origin, seems to embrace ideas of extent and depth, as well as of production or generation. Bochart and others suppose it derived from a Syriac word which signifies to 'encompass.' This is probably consequent on the use of the word among the Greeks, who supposed the ocean to encompass the land, as its connexion with production appears to be the result of the mythological transmission of the history of the general deluge. In its largest extent it is now taken to mean the whole body of water on the surface of the globe, the surface drainage of those portions entirely surrounded by land alone excepted. It has been usually divided into five parts, all retaining the general appellation—the Atlantic, the Pacific, the Indian, the Arctic, and the Antarctic; until lately their respective limits were very indefinite, but in 1845 the Royal Geographical Society of London appointed a committee to consider the subject, and their report is thus given in Johnson's *Glossary of Geographical Terms*:*

'That the limits of the Arctic and Antarctic Oceans, respectively, be the Arctic and Antarctic Circles; that the limits of the Atlantic on the north and south be the Arctic and Antarctic Circles, that its western limit be the coast of America as far south as Cape Horn, and thence prolonged on the meridian of that Cape until it meets the Antarctic Circle; that its eastern limit be the shores of Europe, Africa as far south as the Cape of Good Hope, and thence prolonged on the meridian of Cape Lagullas, till that meridian cuts the Antarctic Circle; that the Indian Ocean do extend from India and Persia on the north to the Antarctic Circle on the south; that its western limit be the shores of Arabia and Africa, as far south as Cape Lagullas, and thence along the meridian of that Cape to its intersection with the Antarctic Circle; that its eastern limit be the west coast of the Birman Empire, and a part of the Malayan peninsula, the west coasts of Sumatra, Java, Timor, and Australia, as far as the southernmost point of Van Diemen's land, and thence continued along the meridian of that point to its intersection with the Antarctic Circle; that the Pacific do extend from the Arctic Circle on the north to the Antarctic Circle on the south; that its western limit be the east coast of Asia and of the Island of Sumatra, the northern shores of Java, Horn, and Timor, and the coasts of Australia, from Melville Island, round to the southern point of Van Diemen's Land, and along its meridian to the Antarctic Circle; and that its eastern limit be the west coast of America and the meridian of Cape Horn as far as the Antarctic Circle. It was further agreed, that the Atlantic and Pacific Oceans be subdivided into three portions —a northern, a southern, and an intertropical—and that the Indian Ocean have but two divisions, an intertropical and a southern.'

It is obvious that such questions as these can only be decided arbitrarily, for it will be observed, that some of the limits given are natural and some artificial, and as without authority the universal consent of geographers can scarcely be expected, it is not only within the province of such societies as

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* We beg to acknowledge here, once for all, our obligations to this very useful and able little work.

the Royal Geographical Society to express an opinion upon them, but the duty of every geographer to submit his individual opinion to their collective decision. If, however, the universal consent of all students of this science is to be hoped for to anything upon its own merits, it might well be to this, for the limits given are, as was to be expected, clear and well defined, and subject to no reasonable objection.

(The Distribution of Land and Water, their normal shape, &c., are treated of in *P. G.*, chap. iv.)

Besides these great and more general, the ocean is susceptible of smaller divisions, dependent like them on the configuration of the land. The next in extent and importance are usually said to be Seas. The word Sea is of very indefinite application, being often convertible with Gulf or Bay. It is used in contradistinction to land in a general sense, and in its special, applied to divisions of the ocean, but apparently without rule. Some seas, as the Mediterranean Sea, are very nearly surrounded by land—some more open, as the sea of Kamschatka. The etymology of the word (from the Saxon *sæ secge*) is rather suggestive of the former, meaning a repository, basin, cistern,—this would, however, include the Gulf of St. Lawrence, Hudson's Bay and Baffin's Bay among the seas. Some lakes have been denominated seas, as the Caspian, and the Lake of Gennesareth, called sometimes the Sea of Galilee. It is much to be desired that some decision was arrived at in this matter by the Geographical Society. The word Gulf is, as has been seen, sometimes used convertibly with Sea; it appears to be properly the intermediate term between that and Bay; it is derived from the Greek, *κολπος*, implying hollowness, depth. Homer uses the word for a bay or creek, (*Il.* b. ii. l. 560,) and it is explained by Eustathius and Strabo to mean a sea enclosed between two promontories; it is generally esteemed to differ from a Bay in being deeper than it is broad at its entrance; the latter word being derived from a Saxon root, signifying to bend, (or possibly from *byge*, an angle)—any deep bend of the sea should in propriety be called a Bay, and in contradistinction to a Gulf, it should be wider at its entrance than in depth; but this definition will not hold good in practice, for then Baffin's Bay could not be so denominated. In the absence, however, of any exact definition of these three terms, the following may be proposed—a Sea, any deep recess of the ocean which may be entered by more than one principal channel; a Gulf, any similar recess, having only one; a Bay, an indentation of the ocean, lying open to it. In case, however, of the adoption of this, or indeed any exact definition, the present names must be changed. The Mediterranean and Red Seas would cease to be so termed, and Hudson's Bay and Baffin's Bay would become Gulfs or Seas. The term Bight is synonymous with Bay.

The passages by which a gulf, or such seas as the Mediterranean and Red Sea, communicate with the ocean are called Straits—as the Strait of Gibraltar. The term strait, occasionally but erroneously used in the plural, is synonymous with channel, it is applied to passages between islands, as well as between the ocean and a gulf, or Mediterranean Sea; and the words Arm and Sound are sometimes used for the same purpose; but the word Channel is equally applicable to rivers, and arm more properly to deep indentations having no second outlet. Strait is the same as straight, and is derived from words which imply elongation (stretching, straining). It is customary to write *straight* when the meaning is direct, *strait* when narrowness is implied, apparently without reason. A strait is a narrow passage, and the word has been applied to a defile or pass, between mountains. The word Sound has a similar derivation originally, but the Saxon *Sund* was used for a narrow sea or *swimming*. A Sound is therefore to be distinguished from a Strait, in not of necessity having a double communication with the ocean, and possibly as being of comparatively little depth—being in soundings, which is usually held to mean a depth of water of not much more than eighty fathoms. (For depths of Ocean, see *P. G.*, chap. v.) In the east of Scotland such indentations or channels are called Firths or Friths, which, if esteemed cognate with the Latin *fretum*, indicate the roughness of the water caused by passing such narrow channels; on the west coast of Scotland and in Ireland, Lochs, i. e. Lakes—the primary sense of this word is to shut in or enclose; and in Norway, Fiords. A small strait is also called a Gut. This word is also applied to the narrowest part of a strait.

The smaller divisions of the ocean, as they are more immediately related to the coast line, in its minute indentations, so they are best described in connexion with the land. Continental land has been already referred to as dividing the continuous surface of the globe into two great parts. All the minor appellations given to divisions of land in extent, excepting those which are properly diminutives, have no relation to size, and are therefore used equally for larger or smaller portions of the same character.

In describing land in extent it is desirable, first, to secure an accurate perception of its general shape, whether it approaches a square, a triangle, or any other mathematical figure, whether it be simple or compound, without paying attention to the minute indentations of the coast. This may be called its normal shape.*

The lines by which this figure is bounded may be measured either from one extreme point to another, or a mean may be taken, the latter plan has been adopted for the descriptive part of this work; their contents should next be ascertained; this may be done by reducing degrees and minutes of longitude and latitude into miles, and proceeding by the rules given, *M. G.*, ch. iv. §§ 2—6, with reference to the scale and projection of the map, by which the calculation is made—(see *Chartography*, p. 178, *et seq.*)—or by simple measurement on an artificial globe.

Having thus obtained a general idea of the shape and size of the land to be described, it must be considered in detail, first marking the larger and then the less important indentations or extensions of the coast-line. The principal extensions of land into the water, for they are applicable to all situations—are called Promontories: the derivation of this word from the Latin *Promontorium* (*pro*, before, *mons*, a mountain), indicates first its origin—viz., from the elevation of the land above the sea level—(this must always be remembered when the shape of land is considered); and secondly, that it is more properly used to denote high land. The word Promontory has no reference to size. The great southern triangular projections of the continental lands already referred to (see *P. G.*, p. 216) are thus named; smaller ones, of course, are very numerous. There are, however, diminutives used in the description of projections of very small size,—a Point is the low extremity of a Promontory,—a Cape (from *caput*, head) is a projection of the coast, or termination of a promontory, neither of great elevation nor yet altogether deficient in it. It may be properly used as a generic term for any projecting land, having no relation to elevation, or as intermediate between Point and Headland, the latter always indicating considerable altitude; a Point of small magnitude is termed a Spit or Tongue; a small Headland, a Bluff—this word is specially localized on the Ohio and Mississippi rivers in America. Foreland is synonymous with Headland, and the word Ness (i. e. nose, a projection) affixed to a descriptive appellation has the same meaning. This word is localized on the east coast as Bill, having the same meaning as on the south coast of England. Spits are sometimes found below Capes and Headlands. The word Tongue is usually the diminutive of Point, and applied to a small extension of low land.

Land projecting into the water, of whatever shape, attached on one side to a larger mass, whether continental or insular, is called a Peninsula, (from the Latin, *pene*, almost—*insula*, an island; in Greek, *χερσονησος*, *chersonesus*,

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* Normal, from *norma*, a square—i. e., right angle, or angular measure—hence the use of the word to signify by rule, on principle, elementary.

land—island.) This word applies to any tract bounded on three sides by water. It is a mistake to suppose that all peninsular tracts of land are united to the main land by an isthmus; some are, it is true; but that which we call the peninsula,—viz., the countries of Spain and Portugal, as being the most important peninsula with respect to England, is not. An Isthmus (from the Greek, ισθμος, a neck or narrow passage,) is a narrow neck of land connecting a peninsula to a continent, or two peninsulas together. It is, however, perhaps more correct to explain the word as meaning a neck of land joining two peninsulas, as a continent becomes peninsular when thus attached. North and South America would be islands if they were not joined by the Isthmus of Panama, or rather of Central America; but the diminutive size of some peninsulas makes the former definition more easy of immediate apprehension, and it is most correct when applied to peninsular tracts in inland seas, lakes, or rivers—the detaching of which from the mainland would not alter its character.

Promontories and Peninsular tracts of land, Points, Capes, and Headlands derive, as has been noted, their extension from their elevation above the water; but land surrounded by it is termed an island, (see *P. G.*, p. 217,) (from *insula*, Latin, any detached place or building.) It is obvious that, if this word be taken in its customary acceptation, the two great continental masses are islands; its derivation, however, shows this to be incorrect, it should be a part of something, because detached. Australia has, therefore, by some geographers been taken from out this category: a glance at the map will, however, show that it cannot be separated from the Malay Peninsula and its appendant islands. A number of islands in near juxtaposition is termed a group—many groups form an Archipelago. This word is, however, more justly applicable to a sea studded with groups of islands. It was originally applied to the sea between Greece and Asia Minor; its etymology is disputed, but it is probably from αρχος, that which rules, chief, and πελαγος, sea; either because of the Archipelago being the chief or most important sea to the Greeks, or because the islands command it.[*] Islands ranged in a line, whether straight or curved, are termed a Chain; such frequently connect a group to the mainland, or promontories and peninsulas to corresponding portions of the opposite coast. The Aleoutian Islands thus connect North America with Asia—the West Indian, North with South America. A small island is called an Islet or Ait; smaller elevations above the water-level, if composed of hard material, Rocks—if of soft, Banks.

Rocks when numerous or extended are called Reefs; when these run parallel to the coast, they are termed Fringing reefs; when they cross or impede a passage, Barrier reefs; when raised by the labour of zoophytes, Coral reefs; and these when depressed in the centre, or raised in a circular form, and inclosing water, are called Lagoon reefs or atolls. Rocks when serrated, or rising in sharp peaks, are termed Needles; to these when isolated, and rising abruptly from the sea, the term *vigia* (from the Portuguese, implying a necessity for watchfulness) is applied. Low rocks lying horizontally, especially when laminated, are called Shelves. Precipitous banks or rocks, whether near the margin of the water, or enclosed, are termed Cliffs, (from the Saxon, implying *cleavage*, i. e. cleft;) when steep and rugged, Crags, (i. e. broken, from the Celtic.) Berg is a German word, adopted with reference to the hilly banks of streams and elevations supposed to be the result of former fluvial action; it is also applied to masses of ice rising high above the water. The term Bank is often applied to portions of the land (either natural elevations or deposited by tides or currents) which are never above the water; these are also termed Shoals, but shoals are generally sufficiently near the

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[*] This word was not in use among the Greeks, and seems to have been brought into the west of Europe in comparatively modern times. It is supposed by some to be the result of mispronunciation of Αιγαιον πελαγος, the Ægean Sea; but it seems difficult to account for the letter π being entirely dropped,—especially if its use be traced to the Italians, the first traders to that sea after the establishment of the Turkish power.

surface to be dangerous to navigation, which banks are not. The word Bank has also the more extended signification—the Banks of Newfoundland, for instance, occupy an enormous area.

As the larger projections and indentations of the land form the divisions of water called seas, gulfs, bays, &c., so there are particular terms applicable to those formed by the smaller; Headlands and capes form small bays; these, if nearly surrounded by land, are called Harbours (from the verb *to harbour*), because they afford protection to shipping. Where protection is afforded from all winds, the harbour is said to be land-locked; where partial protection only is afforded, it is called a road or roadstead; this word is also applied to any portion of the water where ships may anchor in safety from some winds; a small harbour is called a Haven, (from the Saxon, *hæfan*, in Welsh, *havyn*, a still place). If a harbour or haven have on it a town where trade is carried on, it is called a Port. Still smaller indentations of the coast are termed Inlets, Creeks, and Coves. The former is more properly used with reference to a small strait. The word creek is explained by its etymology from the Saxon *crecea*, a crack, and is therefore deeper and more irregular in form than a cove. Cove is the diminutive of bay, and indicative of an arched form. If access to a harbour or inlet of the sea, or river's mouth, is impeded by a shoal, or bank, or reef, the impedient is termed a Bar, because a barrier; these are described according to character and position, whether they are rocky, sandy, or muddy, shifting or permanent, central or on one side.

The margin of the sea is called a littoral, coast or shore. The Latins used the word *litus*, from the verb *lino lĭtum*, signifying to overlay, to anoint, for the line of the land which is washed by the sea; hence our word littoral. It is termed by sailors the sea-board. The Austrian Provinces on the coast of the Adriatic are especially termed 'littorale.' The word coast is derived from the Latin *costa*, a rib, which was applied to the margin of the sea, probably because it encloses or bounds the sea. The modern acceptation of the word is, however, somewhat more extended. It is applied to all land near the sea, and is synonymous with, but more commonly used than littoral; while the word shore is applied to the part which is washed by the waves (yet the expression going ashore is equivalent to landing). Shore is applied to lakes, but coast is not. The word Coast is also, but with less propriety, used for the districts adjacent to the boundary or frontier of any country whether limited by sea or land.

The coast line is the line drawn on maps and charts to indicate where land and water meet. The expression, line of coast, is more general. A coast is said to be high or low, rocky or sandy, continuous or indented, concave or convex, fertile or barren.

The character of the coast is important with respect to the commerce, as well as the defence of any country, it should, therefore, be always carefully described. This may be done under three heads, as suggested in the *Glossary of Geographical Terms* already referred to, and as, indeed, all land ought to be described.

1. The outline or plan of the coast; 2. The profile; 3. The composition.

The first has reference to extent, the second to elevation, the third is more properly geological.

The shore is said to be shelving or steep-to, according as the angle formed by it with the water line is small or great.

When shelving, and alternately covered and exposed by the ebb and flow of the tide, it is called a Beach, (possibly derived from the Saxon *bec* or *boc*, equivalent to the Greek *φαγος* in the sense of corroding, it being washed away or altered in form by the waves.) If composed of small stones, it is termed shingly, (perhaps from the Greek Σχιζω, to divide.) The adjective muddy is sometimes united to the word shore—a muddy shore is when a continuous bank is formed by the current throwing up the mud brought down by the rivers, as on the coast of Guiana; this, as will be seen, frequently alters the course of the mouths of the rivers themselves.

The action of water in wearing away parts of the coast of the sea, or shore of a lake or river, exposed to its influence, is termed (from the Latin) abrading or abrasion. (See *P. G.*, p. 254.)

When the water forced by the tide, or wind, or even by a current, over rocks or shoals, foams and roars, the term Breakers is applied to it, and sometimes, but incorrectly, to the rocks or shoals. When, in like manner, it breaks directly on the shore, the word Surf (? from the French *sur-fait*). The flow of water in one direction is called a Current, when forced rapidly between parallel ledges, or reefs of rocks, or sandbanks, a Race. When the tide wave, compressed in a narrow channel, rises with great rapidity and a terrible noise, it is called (from the Saxon) a Bore. (See *P. G.*, p. 232.) This is to be observed in the extremity of the Bristol Channel, the Bay of Fundy, and, more or less, in all similar situations, especially where exposed to the direct action of the tidal wave. When by the force of the tide or current pressing the water diagonally against the shore, or between rocks or banks, a circular direction is given to it, or where a similar effect is produced by the meeting of two currents, or by deep holes producing a downward suction, this is termed an Eddy; in the latter case, when very large and powerful, it is called a Whirlpool. These words are used indifferently with respect to both salt water and fresh, to lakes and rivers, as well as the ocean.

5 *Of Land in Elevation.*—Under the appellations which have been explained are included all that relates to extent of land, and by which it may be described in that relation. This is, however, rather apparent than real, being, as before observed, entirely dependent on contour, or the elevation and depression of its surface; but as the level of the sea is the apparent limit of the land, all beneath it belongs more properly to the division of Marine Hydrography. From the horizontal profile of the land, description must proceed to that on which it depends, the vertical profile. From the level of the sea the land rises irregularly. The highest elevations appear to man much more considerable than they really are; he judges of them by their relative proportion to himself and the limited sphere of his own observation, and not with reference to the globe on which they are raised. When their height is estimated by this rule, it will appear that though on the elevation of the land all its other superficial features depend, as well as those of the water by which such large portions of it are covered, yet that they are relatively very inconsiderable. Kunchinginga, which is now generally considered to be the highest mountain in the world, is about 28,177 feet in height; the mean diameter of the earth is 7912 miles; but estimating the greatest elevation on the surface of the globe at 30,000 feet, and the diameter at 8000 miles, to make the relation more apparent, the proportion will be as 30 to 42,240, or 1 to 1408. Mr. De Morgan, in his very able work *On the Use of the Globes* (c. iii.), gives the following calculations with reference to the irregularities of the Earth's surface:—'The Earth is really a slightly flattened sphere, having the axis passing through the shortest of all its diameters. The shortest radius, or semi-diameter, being half the axis, is 3949 miles. The longest, which belongs to the great circle having the ends of the axis for its poles (called the equator), is 3962 miles. On a globe of eighteen inches in diameter, this difference of thirteen miles would not amount to so much as the thirtieth of an inch, and it would be altogether useless to take any account of it. (See *Chartography*, p. 179.) We shall then suppose the Earth to be a sphere, with the mean semi-diameter of 3956 miles, so that, roughly speaking, 1000 miles are 2¼ inches, (more accurately 2·275 inches.) The mountains are not represented; one of thirteen miles high (and we know of none such) would not prick the fingers through the varnish with which the globe is covered, which, therefore, much more than represents a universal deluge. Supposing the atmosphere to be forty miles high, it would nowhere rise a tenth of an inch from the globe.' With such knowledge, the inconsiderable relation of the highest elevations to the size of the globe need not be insisted on, but in their relation to Physical Geography, and to man, they are of the greatest importance. The tendency of water to seek its level makes

the position and quantity, as well as character of the waters of the globe, dependent on its contour; every conical projection, every ridge, in short, every elevation of what sort soever it may be, becomes a watershed; and that knowledge of the height, slope, and direction of the various watersheds of the Earth's surface the first step to its general contour. The word watershed in geographical definition, implies the line by which any waters are divided from each other, and the watershed of any country is no doubt such a line; but as every slope sheds water, and many rivers have their rise on slopes below the main watershed, some further division of the word, some classification of the districts to which it is applicable, appears highly desirable. As this does not seem to have been ever attempted, the following is offered as a suggestion:

That there is a line in every country, which may be termed its principal watershed, will not be disputed; every country has some one district, usually in the direction of its greatest length, more elevated than another, from the sides of which the waters collected from snows, dews, rain, and springs, pour down, until they are received into the basin of some inland water, or at last into the sea; this may, therefore, be properly termed its primary watershed; but, as the mountains of the world cannot be satisfactorily considered except in their relative connexion, the highest ranges extending through the greatest length of the continental masses, the term primary watershed should be confined to these; beyond them others of less considerable elevation are found, the slopes of which are presented towards the primary watershed and form with it deep hollows, into which their united waters are poured, while from the opposite slope the waters collected descend in a different direction. These may, not inaptly, be termed secondary watersheds, as paying the tribute of part of their waters to the primary, and forming the inferior limit to the principal river basins; while others rising beyond may be called tertiary. It will be observed that this classification affords not only a systematic division of the elevated land, but also of the waters of the globe; as appertaining to any of its parts, rivers having their rise in the primary watersheds may also receive a similar designation, as may their basins; others may be termed secondary or tertiary, according to their position and the watersheds to which they belong.

The highest elevations on the surface of the Earth are called Mountains, but this term is applied to elevations varying from less than 3000 to more than 28,000 feet, and it has long been a difficulty in geography to find an accurate definition for this word, which, derived from the Latin *mons,* (*quasi μονος,* as standing alone,) was applied originally to very inconsiderable elevations. Mountain and Mount appear to differ from each other in the latter being single, and the former, possibly, collective; many mounts may assist in forming a mountain; but in the lower elevations the words mountain and hill are used synonymously, as we say, the Welsh hills or the Welsh mountains. Some have proposed to confine the word Hill (Saxon, from a root signifying elevation, or, possibly, to hide,) to summits not rising more than 1000 feet above the level of the sea. If this were done, some classification of mountains besides that of elevation above hills, would still be necessary. Others have been disposed to regulate the application of the term by the geological structure of the elevation in question, esteeming mountains the effect of upheaval, hills of denudation, but this could scarcely be a test of its geographical propriety; for the same reason the connexion between the classification proposed and the geological characteristics which may be traced in its divisions, is not more enlarged upon, but taking the primary, secondary, and tertiary watersheds of the Earth as mountains, and all others as hills, we shall find the former ranging, on the average, above, and the latter below, 2000 feet. In lands detached from the great continental masses the mountains may be classified with the chains of which they are extensions, and thus opportunity will be afforded not only for systematic arrangement but systematic comparison. Undulating grassy hills are in

England called Downs; undulating sand hills, in some localities Dunes—words of kindred origin with the English *down* as opposed to *up*.

To describe the configuration of the land in its varying contour, many terms have been adopted by geographers. A more or less conical summit is called a Peak; a connected line of summits, a Ridge, or Range; to such, if they present many peaks, the term serrated (from the Latin *serra*, a saw in Spanish *sierra*,) is applied. Crest is a general term for the highest part of a mountain. A Pass is, as the meaning of the word would suggest, the place between the peaks, or higher elevations, where a mountain-chain is passable. Passes are usually at the angle formed by one part of a chain with another, or of a main chain with its spurs or branches, and consequently being at the head of valleys, are also (as will be seen) at the head waters of rivers. The word Branch is, however, more applicable to a river than a mountain. A pass was sometimes by the ancients called a gate, (by the Greeks, *πυλων*, *pylon*,) as it is now by the Spaniards; *port* is used on the Pyrenees, *pertuis* on the Jura; its French equivalent is *col*, narrow; a pass, or portion of a pass, more narrow than the rest, is termed a *Gorge*. This term belongs more properly to the channels of the upper waters of the smaller feeders of rivers and mountain torrents. It differs from a Defile in being always near the summit of a mountain, while the latter name is applicable to any narrow passage between precipitous rocks, especially if long and winding. All these terms appertain to mountains.

Both mountains and hills are the boundaries of valleys. The term Valley may be applied to any depression on the surface of the globe. The largest valleys form the beds of the great oceans. Seas, bays, gulfs, &c., are all valleys below, or partially below, the level of the sea. Valleys, in the common acceptation of the word, are those depressions which are observable above the sea level, and which form the beds of rivers and basins of inland seas, lakes, &c. They will naturally class themselves with the watersheds to which they belong. Those which lie between the primary and secondary ranges, and form the beds of the principal rivers, will be classed first. In Europe, for instance, we find four principal valleys, those of the Danube, the Rhine, the Rhone, and the Po. Valleys have been divided (see Johnson's *Glossary*, pp. 44, 45,) into principal, whether longitudinal with, or transverse in their direction to, the mountain-chains by which they are bounded; lateral valleys, those of inferior order, which join the principal; high, or mountain valleys; and low, or valleys of the plains. These terms, however, are rather descriptive epithets, and explain themselves, but do not afford any regular classification. Apart from their relation and position with respect to mountain-chains, valleys differ from each other in depth and shape as well as extent. The most important distinction to be remarked is, whether, as is most usual, a valley gradually expands from its upper extremity to its mouth, or is bounded and partially enclosed by lateral ridges, or even so surrounded as to afford no outlet for its waters. In the latter case, it was proposed by Malte Brun to call the lakes which such valleys usually contain Caspians. The word valley is from the Latin *vallis*. Vallum seems to have been applied indifferently to the ditch or the palisade, by which the Romans surrounded their camps. Vale is the diminutive, and is more properly used with reference to the undulating depressions between hills. The word intervale is used in America to signify the tracts of rich alluvial land often found in valleys; it has occasioned some difficulty, and has been variously explained. Dugald Stewart esteems it equivalent to '*inter vallos Spatium*,' the space between the palisades, and remarks that, having been first used to denote a limited portion of longitudinal extension generally, it became afterwards more usually applicable to portions of time.

Valleys seem to demand a double classification; first, with reference to position; secondly, as to character; the latter being in no manner dependent on the former. Valleys containing their own system of waters are found below the level of the sea as well as on high mountains, while those which have only a narrow outlet may contain either a river or a lake. This, however, offers a characteristic sufficiently well defined. Valleys may therefore be described as lake or river valleys; these, again, as longitudinal or circular, confined or open. The term basin might have been used with much propriety for enclosed valleys, had it not been adopted to express the whole surface drained by any system of waters (see *P. G.*, c. v., pp. 233, 239.) The word basin (possibly from the Greek *βασις*,) adapted from *bassin*, (Fr. basin or bowl,) has been defined (Johnson's *Glossary*, p. 10) as a more or less extensive, and more or less concave portion of the Earth's surface circumscribed on all sides, or on all but one, by watersheds, and formed of all the slopes whose waters are received into a common receptacle, whether this be a river, lake, or inland sea. Basins may be classified as lacustrine or fluvial, equivalent to lake valleys and river valleys. The word is also applied to valleys below the level of the sea, and may be Oceanic or Mediterranean. A fluvial basin may be either the confluence of all the valleys which unite their tributary waters in one stream, or each valley by itself; or, in general terms, it may be applied to any well-defined direction of the course of a river formed by lateral shores from the main watershed, thus it is not unusual to say, speaking of a river, 'the basin of its upper waters.' Lacustrine basins are, more properly speaking, those which contain caspians, or lakes which have no outlet for their waters, but it is not confined to them.

The watersheds are then the limits of the basins, the character of which determines that of the waters which are found in them; but not unfrequently sloping at a very small angle with the level of the sea, they spread out into extended tracts, to which various names have been given descriptive of their character, but varying with the locality and the language of the inhabitants. The words plateau (from the French) and table-land have been already applied (see *P. G.* p. 223) to tracts of considerable elevation and of small inclination. These may be on the tops of mountains or on their sides; plains are to low land what plateaux are to high land. The whole surface of the globe may be divided into hills, valleys, and plains; but very widely extended valleys, as in North and South America, become plains, from the extent being more than commensurate with the height of their watershed. Plains may be crossed by hills, may be undulating or flat, fertile or sterile, wet or dry; if green and even partially fertile, they are in North America called Prairies—i. e., meadows. These are classified as dry and rolling, or wet; to the latter, perhaps, the term Savannah would be most properly applied, for damp grassy plains are so called in America. On the contrary, Llanos are, like the former, dry; such are to be found in all parts of the world near large rivers alternately fertile and arid. To the south of the river Amazon, they are called Pampas, a word used indiscriminately for the raised surface of the great plains which extend from that river to the Straits of Magellan. The former appellation is more properly confined to the valley of the Orinoco; the latter to that of the La Plata. In South-eastern and Asiatic Russia, similar tracts are termed Steppes, (from *step*, barren, Russ.) The term desert is usually applied to vast tracts covered with sand. These, however, have not an unvaried character, fertile spots are occasionally met with wherever, from any cause, water is present. All these tracts derive their appellations from their leading features. The word wilderness differs from desert, in being applicable to land covered with spontaneous and abundant vegetation, as well as to wild barren spots, among rocky mountains, as in the peninsula of Arabia. In India, a wilderness (usually found in moist places) is called a Jungle. Plains covered with low plants are in France termed Landes; in Germany, England, &c., Heaths, from the plants most commonly found on them. Land having its surface saturated with water, 'which from the concave form and impermeable nature of the bottom does not drain away,' is termed a Swamp or Bog; the latter, of Celtic derivation, indicates its binding and tenacious character, the former (Saxon) its spongy nature. The term bog is generally thought to imply a peat formation, while swamp is used more generally. Swamps may have trees growing in them (cedar swamps are common in America). Marsh is from a Teutonic root, and nearly allied to moor; it has generally a flow or rivulet running through it; by some, marsh is thought to be the generic term, and is also used with reference to meadows occasionally overflowed by the sea, or under a system of salt-water irrigation, which are called salt marshes. Fen is applied generally to low moist lands.

Having explained the terms used in describing land in its vertical contour and varying character, we proceed to those used with reference to water above the level of the ocean. The water on the face of the Earth is either at rest or in motion.

6 *Of Water not in Motion.*—Dew and rain falling, and snow melting in water, on the surface of the globe, collect in hollows, or trickle down in rills; or again filtered through its superficial strata, form Springs, (see *P. G.*, pp. 209, 211, 238.) Small bodies of water collected in hollows are called Pools or Ponds, the former when they are filled with running water, the latter when isolated, though a very small pond is often called a pool. The bed of a river, when partially dry in summer, often presents a series of pools; these would be erroneously termed ponds. A large pond is a small lake. These are not the converse of islands, inasmuch as they are not always, nor indeed very frequently, surrounded entirely by land, as islands are by water, but receive into and emit water from them. Lakes may be described in position, from the watershed to which they appertain. In character—they are of four kinds:—

First. Those which neither receive nor transmit water, i. e. which are neither fed by nor are the source of streams—such lakes are more commonly found in mountainous countries, are generally of small dimensions. Lagoons are sometimes similar in appearance, but owe their existence to the infiltration of water from, or the overflowing of, either the sea or rivers; they are therefore usually found in low lands. Lagoons are for the most part shallow, frequently dry up in summer, not unfrequently at one time connected, and at another disconnected from their parent waters. This is the case at Holyrood Pond, St. Mary's Bay, Newfoundland, the entrance to which being formed in winter by the force of the waves, is annually stopped up by shingle in the summer, and affords the inhabitants a plentiful supply of fish, which are thus placed at their mercy: it was formerly an arm of the sea, and many similar lagoons are formed by the blocking up of small harbours, creeks, and channels by sand or shingle. Lagoons, though having thus an apparent relation to, are not to be arranged in the first class of lakes. Lakes and ponds being the result of surface drainage; lagoons, of overflow or infiltration.

Lakes, of the second class, are those which receive into, but do not emit water from them. These are usually salt and brackish, often found in mountainous districts, high above the level of the sea, not unfrequently the result of volcanic action; sometimes below the level of the sea, as Lake Asphaltites in Palestine, erroneously termed the Dead Sea, and the Caspian. Lakes of this class are the receptacles of inland systems of waters and rivers which do not communicate with the ocean, (see *P. G.*, p. 218.) The third class is formed of lakes which do not apparently receive, but emit their waters; some do so by subterranean channels, as Lake Copais in Beotia did, and Lake Jouxin does. Lakes of this class are usually found at the head of rivers, especially in the passes of the primary mountain chains, frequently, as in the Rocky Mountains, at the sources of the Saskatchevan and Frazer's rivers, and in the Alps at those of the Inn and the Po, in immediate proximity to each other, while those rivers which issue from them fall down the opposite slopes of the watershed. The word Portage, i. e. carrying-place, is applied to the land between two such lakes, as also between any streams or lakes, or the passage round a waterfall or rapid, where it is necessary to carry boats or canoes and launch them again, to continue the inland navigation. The fourth class is the most numerous, consisting of lakes which both receive waters into and emit waters from them. These are common in the middle and lower courses of great rivers. When following each other in succession, or clustered together, the same terms, chain and group, are used which apply to islands. A chain of small lakes linked together by a river or stream, is called by the Germans a chaplet river. Where, in America, a river in its tortuous course forms a deep and wide extending bend, the same term is applied which we use in similar cases with respect to small streams; it is called an Eddy; this is correct; for great and small are only relative terms, and both are the result of the same kind of action, only on a different scale.

The water of lakes is subject to the same definitions and description as that of seas and oceans; the irregularities of their outline are expressed in the same terms, but the word shore is more generally used to express the margin or border of a lake than coast. Some lakes have, as has been noticed, the level of their waters below that of the sea, but the majority are raised above it; many, however, have the bottom of their basins below that level. Lakes in Scotland are termed lochs. The term lacustrine is applied to whatever belongs to, or is connected with, a lake, as Lacustrine basin, &c.

7 *Of Water in Motion.*—Water running down the sides of mountains, hills, or other sloping grounds, collecting in small channels, forms Rills, Streams, or Rivulets; the former is from the German, meaning a groove or channel (or possibly from the Scandinavian *strila, ryller,* to run or glide), the latter the diminutive of river. Stream is Saxon, and used as a generic term for water in motion, whether salt or fresh, without reference to magnitude on the cause of motion.

Streams which flow into other waters are termed affluent, when they flow from them effluent. Tributary streams are those which contribute their proportion to any lake, river, or collection of waters. It has, however, been justly remarked, that 'a tributary is not necessarily an affluent, though an affluent must be tributary,' for an affluent may receive the waters of other streams, and convey them to one common recipient, to which they would all be tributary, while to it they would be affluent.

The term effluent is equivalent to branch, which is not applicable to an affluent; the branches which rejoin the parent stream are called 'ana' branches;* those which at the mouths of rivers enclose and divide triangular tracts of land, to which from the Nile the term delta (the Greek Δ) has been applied, are called deltic branches; those which divide a delta into islands, but return again into a deltic branch, not flowing directly into the sea, ana deltic; those which connect two rivers together, conjunctive branches; and those by which water from the main stream is drained off into marshy or sandy places, drain branches.

The terms convergent and divergent should be applied to waters flowing into or out of a river when their character is not known; it is obvious that the one may be an affluent or an ana branch, the latter a deltic, drain or ana branch; these terms are, therefore, important in the exploration and the description of countries imperfectly known. When a river spreads into two branches, it is said to bifurcate, (*bis*, twice, and *furcus*, a fork, Latin, a pleonasm.) A bifurcation is usually a branch, and confined to the same basin as its parent stream; but in some cases, as in that of the Cassiquare, by which the waters of the Orinoco are connected with those of the Maranon or Amazon River, it connects two basins together. This term has, but without necessity, been applied to mountains. The junction of streams is termed their confluence, (*con fluo*, to flow together;) this frequently gives local appellations to places; in Welsh, names beginning with Aber indicate such a position.

The difficulty of classifying elevations of land and of applying the

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* Ana, said to be a contraction of anastomosing, anastomosis being in medicine the inosculation (στωμα, a mouth, Gr.) of vessels together, or of veins with arteries. This is, however, unnecessary, for ανα, in composition, signifies back again, or in return, and such branches bring back again the waters which they before had taken away.

names used to express them, has been already noticed. The difficulty is as great with respect to running water. Estimated by comparison, many rivers should have diminutives applied to them. Compared to the Amazon, the Thames is but a brook, yet here the Thames is an important river. The difficulty is, however, capable of the same solution. The classification of watersheds gives at once a classification of rivers. A river (from *rivus*, Latin, a channel) is a collection of small streams or rivulets; many small rivers may combine to make one large one. The use of the word is not, therefore, confined to a main stream any more than it is dependent on proportion. That from which a river takes its rise, whether spring, lake, swamp, or glacier, is called its Source. Most rivers have more than one source, and as in the case of the Mississippi, the name of the least importance is sometimes selected to designate the whole. The principal source is to be ascertained by its elevation, distance from the mouth, and by the volume and character of the water it contributes. The junction of a stream with the recipient of its waters, whether river, lake, sea, or ocean, is termed its Mouth. This is, however, only applicable as opposed to Source, for some rivers flow through lakes and marshes. Rivers can have many sources, and may have several mouths, but the words can only be used with reference to their extremities. The mouth of a river is also called, from the French, its *embouchure*. This word is applicable to the mouth of a river, whether it be in a lake or in the sea; but when, flowing into the sea, the mouth of a river is modified by and subject to the influences of the tides, it is termed an Æstuary, a name derived either directly from *æstus*, the tide, or from *æstuo*, to boil, (Latin, implying restlessness,) and thus indicative of the effect of the tidal wave meeting the current of the river. The expression, Course of a stream, implies its direction, its current, the motion of its waters. This varies much in different rivers and in different parts of the same river, and is a marked and important feature to be noted in all, especially its rapidity as indicative of the elevation of its source.

Fluvial, fluviatic, and fluviatile are adjectives, expressive of formation from, or connexion with, a river, as fluvial delta, fluviatile lagoon, fluviatic formation; the first is most appropriate.

Rivers which have their rise in the primary watersheds of the globe have themselves the same appellation. This class will be found to include all the largest rivers in the world. The secondary watersheds will give their appellation to the rivers which are derived from them, and the more navigable portion of rivers will usually be found without their limits, and so on, but no classification or distinctive appellation has yet been suggested with reference to the character of rivers. This is yet a desideratum, (see Johnson's *Glossary*, on the word *River*, p. 39;) some approach to it has, however, been made by dividing the course of rivers into three parts—the upper, middle, and lower. This, however, can only be done satisfactorily when a river is connected with more than one watershed. There is, however, another classification, which is most important, in considering the globe in reference to man—rivers are navigable or not. A navigable river may be so from the sea, or only inland, or both; its navigable character may be consequent on its natural depth, or the effect of the tidal wave; in any case the consequences will be important to the country through which it flows.

The cavity in which a river flows is called its Channel; the bottom of the channel its Bed; the sides its Banks; (*bank*, Saxon, a bench, mound, or pile,) both are of importance in the description of a river. The first regulates its depth; if rocky and broken, it forms a rapid or fall; if level and extended so that it may be passed on foot, a ford. The banks may be sloping or steep, rocky, or fertile: if sloping, the waters may be extended; if steep, and especially when approaching the perpendicular, they will be confined, and not unfrequently the compression of water between high rock produces apparently a fall of water. This in North-west America is called a Cañon, from a Spanish word meaning a cylinder, or bore. The bed and banks of rivers vary much in different parts of their courses, and are dependent on the profile and character of the country through which they flow. Sudden irregularities of the surface produce some of the most important features in the description of rivers—the fall of water over rocks. To characterize this, various names have been given. A Cataract is a large body of water precipitated from a considerable height; the word (derived from the Greek, *καταρακτος*) implying force, violence, power. A Cascade is a small cataract. In cascades the water sometimes descends by successive leaps. A Leap is the fall of water, unbroken, from an inconsiderable height. A Force is the result of the narrowing of the bed of the stream; it differs from a cañon in being of less extent. Of all these the generic term is Fall, which has no reference to character, elevation, or volume of water, being applied indifferently to a mountain stream and to the Niagara, to the Falls of Wilberforce and of the Clyde.

8 *Of the Natural Productions of the Surface of the Earth.*—In the description of the characteristics of different parts of the Earth's surface—the opposite features of fertility and sterility have been already noticed,—these not only involve, of necessity, all the intermediate stages of vegetable productiveness, but the kind as well as quantity of the vegetable produced. Fertility is always the result of moisture, in river or lacustrine basins by the waters they contain; it is so even in the smaller, as when in deserts either a depression of the surface, a quality of soil more capable of retaining moisture, or the presence of a spring, produces those oases (*habitable*, from the Coptic) in which the contrast of the verdure they present, and the refreshment they afford with the arid waste by which they are surrounded, is so grateful to the traveller. In plains, vegetation is kept up by the plentiful dews which fall upon them. The valleys are, as has been noticed, connected together by their head waters being in the gorges or passes of the mountains, often in close proximity. Plains are always passable.

Animal life depends on the nature as well as the quantity of vegetation, and thus man partakes of the characteristics of the soil which gave him birth. Not only, then, shall we find the proportion and relation of land and water depending on the contour or profile of the former, but the vegetation, and consequent on that, the animal life;* and lastly, the human beings whose existence depends upon them, and whose character is modified by them, not less than by the communication which can be maintained between different parts of the earth; the consequent dispersion of mankind over its surface; and the subsequent spread of civilization and religion. From the consideration of the horizontal profile of the Earth's surface, it was natural to proceed to its vertical; the next step is the knowledge of its productions, which leads as naturally, as it does imperceptibly, to that of its inhabitants. Among those productions, it will, however, be necessary to include some minerals, especially gold, iron, and coal, as having exercised a direct and powerful influence over the progress of population in the world.

These subjects have been treated of generally as a part of Physical Geography; it is not necessary here to enter more into detail, and to explain the terms employed in the description, as in the case of land and water. They being generally well known, and not belonging solely to Geographical Description, while some have technical or local application, which will be noted in the proper place; of some, as prairies, savannahs, silvas, heaths, &c., notice has already been taken, (see *P. G.*, p. 218 to 225.) In this place, therefore, they need only be referred to. The word Forest (of a Latin or Celtic origin, but in any case from a root signifying to depart, and hence in the Romance languages equivalent to *strange, foreign*) is applied, in Geography, to an extensive tract of land covered with trees. In law and custom in this country, tracts of land which have had those rights, under the laws for the preservation of game, which entitled them to the appellation, were and are still called forests, though some-

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* See sections in *Physical Geography* on distribution of vegetables, &c.

times without trees; hence barren tracts, as Exmoor, obtain that name. The Saxon term Wood, which has naturally no relation to size, is now used to imply a smaller extent of surface covered with trees than is meant by forest. In the description of forests and woods, the most important consideration is the character of the trees of which they are composed, to what use the timber they produce can be applied, whether it is capable of supplying the wants of man, and therefore whether it invites man to its own destruction and extends his influence over the face of the Earth with commerce and civilization. These are, perhaps, more influenced by the forests of the globe than by anything else, for though the path across plains is open for man and beast, and the head waters of rivers direct to the practicable passes of the mountains, yet an easier and more direct path is afforded by the sea, by which the richest and most productive soil, the alluvium about the lower course of the rivers, is brought into use, and the mouths of rivers connected together, as their basins are by the mountain passes; to avail himself of this facility, man requires ships, and thus maritime nations have perhaps owed their possession of that most desirable characteristic to the presence of timber fit for ship-building. It was so with Hiram and his Phœnicians, it is so with us and our American brethren. Forests being inhabited by beasts of chase, producing also a race of hunters; as plains feeding cattle are inhabited by Nomads (from the Greek, νεμω, to divide, distribute, and thence to wander and to feed cattle.) In like manner soils capable of producing cereal plants, or others fitted for the food of man, have a tendency to locate men upon them. Hence cities have first sprung up in fertile valleys.

It has already been shown (see *P. G.*, ch. 10. § 129) that limits are assignable to the productions of most vegetables—these limits enclose tracts called zones, and vary, as has been shown, from position and elevation; both have respect in some degree to climate and soil. It has been noticed that the cereal plants, with some other species, as well as the domesticated animals, have followed man in his progress over the globe. They should, therefore, be noticed in connexion with him and his works; apart from him those only of indigenous character ought to be noticed. Yet where he has not been, the character of the indigenous vegetable and animal life is an index of what he may, with ease and propriety, introduce into any country; and not unfrequently the peculiarities of animal and vegetable life affect the habits and character of man to an infinite degree. The moss of Lapland, and the reindeer, from which it takes its name, and whose food it is; the camel and the horse, the date-tree and the coffee-plant of South-Western Asia; the llama of South America, and the bread-fruit-tree of Polynesia, may be cited as marked examples, all probably indigenous, as the horse, sheep, and cattle of America and Australia, and the potatoe of Ireland, are exotic. The limits of some of these and similar natural agents affecting the life of man, both social and political, will be found clearly defined in the atlas adapted to this work, and in most physical atlases. From it, in connexion with the chapters on Physical Geography, sufficient general information may be obtained on this subject; its application in detail must form part of the description of different countries, and will be considered as it affects them separately.

CHAPTER II.

1. Of political geography. — 2. Of historical antecedents.—3. Of the distribution of the human race. — 4. Of geographical statistics. — 5. Of the order to be observed. — 6. Of the civil divisions of the world. — 7. Of the civil divisions of countries. — 8. Of religious divisions. — 9. Of the dominant religion. — 10. Of religious sects. — 11. Of religious statistics. — 12. Of the industrial geography of countries. — 13. Of industrial divisions. — 14. Of occupation. — 15. Of the pastoral. — 16. Of the agricultural. — 17. Of the manufacturing. — 18. Of the commercial.

OF *Political Geography.* — Political Geography has been defined (see *Admiralty Manual of Scientific Enquiry—Geography*, p. 129) as including 'all those facts which are the immediate consequences of the operations of man exercised either on the raw materials of the Earth, or on the means of his intercourse with his fellow-creatures.' This corresponds to the division already made—namely, 'the effect of man's residence on the Earth;' and this may with propriety be, in the widest and most comprehensive sense, termed political. It has, however, been customary to apply the term political principally to the geographical divisions and limits of empires, kingdoms, and states, their laws, mode of government, &c.; but as the polity of some countries has a religious, of others a commercial basis; as in some countries the religious system is separate and detached from the civil, in others a military rule has been superimposed upon previously existing civil and religious institutions; as in one country one predominates, and in another country another; the adoption of this without subdivision does not seem likely to conduce to a clear understanding of the subject. Man in his works, as apparent on the Earth, may perhaps be most usefully considered in three relations—religious, civil, industrial.

2 *Of Historical Antecedents.*—As in few cases, if in any, the geographical limits of the three divisions will be found to coincide with each other, the arbitrary division of the Earth by its rulers having generally been made to suit present interests: seldom, if ever, the physical features and natural relations of countries, or what is equally important, their natural divisions, still less the relationship or dissimilarity of their inhabitants: in short, the interest of the few having been consulted, and not that of the many, it will appear necessary to look back on the history of countries and their inhabitants, in order that their present anomalous condition may be understood; for not uncommonly it will be found that, in consequence of the different circumstances in which they have been placed, and the different rule under which they have existed, races similar in character and origin are found in very different stages of progress; so different, indeed, that they present no outward indications of their relationship. It is naturally the part of Geography to show how these changes have been affected by the physical character of the countries which the people in whom they are observable have inhabited; of History, to inquire into the political causes properly so called. Yet these two branches of the subject cannot be entirely separated, the physical may depend on the political; despotism, whether civil or religious, may prevent the gifts of God from being turned to account: anarchy may destroy what has already been raised by the industry of man; the fertility of Egypt has since the time of Joseph been the cause of the oppression of its people; the desolation of many parts of Italy is the consequence of the dominion of Rome, whether imperial or papal, commencing with its rise, and continuing to the present time. If, therefore, we would comprehend the present condition of the surface of the Earth, an historical inquiry into the changes which have taken place upon it during 'recorded time' must precede its description. This will affect different parts of the

world in various degrees. Of the past history of many parts little is known; of some, nothing. Yet even where little is known, indications are not wanting of the importance of the past. Of this, the remains of an extinct race recently discovered in the valley of the Mississippi will afford sufficient evidence. Our knowledge of the ancient world is, for the most part, confined to the accounts of the Hebrew, Grecian, Roman, and Alexandrine writers, and limited to the extent of their information, the boundaries of the Persian, Macedonian, and Roman empires, with the inroads and incursions of their rulers on the neighbouring countries, and the discoveries of Phœcinian, Cathaginian, and Egyptian mariners; and on this account, as well as because its application is principally in illustration of their history, Classical Geography must assume a more topographical form, and will be presented in the first place and by itself, that it may form a satisfactory basis for further inquiry. In it, however, as of universal significance, the division and dispersion of mankind, and their effects upon the world, cannot be fully treated of, although they may be noticed. A general sketch of these great influences must therefore precede the consideration of the political state of the world in modern times, as that must be preluded by a general description of the features and character of its surface; and the same method must be followed in detail with reference to every separate country; whenever it is desirable or possible to extend it so far; the political inquiry will then follow easily and naturally.

3 *Of the Distribution of the Human Race.*—To the various families of the human race, their physical and mental characteristics, and the natural laws to which they are subject, general reference has been made in the chapter on Ethnology (see *P. G.*, p. 388). This has of late years taken its place as a separate science, and it is not therefore now the province of Geography to enter into the philosophy of the subject, with respect to man as an animal, but to state what is known of the present localization of his species, and the geographical causes which have led to it. The former has been described generally, and must be more particularly detailed with respect to every country as it comes under review. The latter will be found chiefly in the configuration of land in elevation and extent, directing migration into certain natural channels, of which the primary watersheds afford general indications; those of the Old World, separating the north from the south, and concentrating the energies of various races round the great Mediterranean basin, thus uniting them all in one common progress; while those of the New World, far removed from its eastern limit, rendering the entire continent accessible by the mighty streams collected from their lengthened slopes, have given facilities for the diffusion of the races of the Old World, developed in physical and mental energies by concentration and collision, over its surface.

The use of the various paths of migration has, however, depended on the power of man to avail himself of them. The great plains offered facilities of migration to the pastoral inhabitants of the ancient world, to whom the seas were impassable. The coasts of the inland waters were therefore peopled long before communication existed between them. The valleys of the head waters of rivers were always, and are now, the only practicable paths across the primary watersheds; by them, therefore, the stream of migration has been permitted to pass, and by them communication is maintained. The valleys of the great rivers have, therefore, received inhabitants from their upper as well as their lower entrances. The proximity of a primary watershed to the coast may, as in the case of Africa and America, entirely cut off one portion of a continent from communication with the other for many years, and therefore cause considerable difference in the character of their population; this is moreover also affected by the varying physical characteristics of the countries themselves, which are again consequent on their vertical contour; and thus it also happens that the commercial exchanges and consequent intercourse of countries is often rather with distant people than with their neighbours.

Since the development of navigation, commerce has been principally carried on by means of the sea; the old paths of inter-communication have been therefore abandoned; modern science has discovered means of cheap and rapid transport over the land, and we may thus fairly expect to see them re-opened. Their disuse caused the decrease of population and civilization in the districts through which they passed, their restoration will cause their re-peoplement and enrichment; and thus Syria, the valley of the Euphrates, Asia Minor, Persia, the Balkan, may before long be again important to the world, as Egypt has already become, and as we see Central America, Upper California, and Texas are becoming.

As the general distribution of the human race over the surface of the earth has been consequent on its larger physical features, so has the local arrangement been upon the presence of agricultural or mineral wealth. Agricultural districts, not requiring a large population, or the possession of the knowledge of mechanical power in any great degree for their cultivation, have been early peopled. It is to the presence of mineral wealth, and the development of manufactures and commerce, that the congregation of numbers in small districts is owing; hence we find the greatest accumulation of men in masses at the mouth of rivers, in harbours, and where natural paths of communication intersect, directed by the necessities of commercial intercourse, or in mineral districts. In ancient times, the presence of gold, copper, and tin exercised great influence on the diffusion of population, and the extension of commerce. To the former is attributable the first efforts to unite Greece with the eastern shores of the Baltic in commercial intercourse, of Solomon to carry Phœnician traffic across the Isthmus of Suez; the commencement of the era in which we live was marked by the discovery of the gold-producing countries of the New World, to which a constant stream of emigration has been since directed, and in our own day California, and possibly Australia, may owe their population to the same cause. Tin and copper have carried the ships of Carthage to England, and the ships of England to the Indian seas, Australia, and America. But since the use of machinery and the application of steam as power, coal and iron have exercised the greatest influence in this respect. Nor is the providence of God in directing the distribution of the human race limited by the supply of the wants of man, the provision for the cure of his diseases has its peculiar influence upon it. Even in savage countries among the natives, as among the beasts of the field, periodical visits to mineral springs have always been observable, and in civilized countries men have always congregated and cities been built around them or in their immediate vicinity, while, too, in smaller degree, even salubrity of atmosphere and beauty of scenery have influenced this localization.

This distribution, as has been already noticed, being irregular both in space and time, it will be found to affect Political Geography in all its divisions. The civil limits, divisions, and polity of countries; the industrial habits of their people; and their relations with others, whether distant or neighbouring, and specially their religious faith and its outward expression, will be found to vary accordingly.

4 *Of Geographical Statistics.*—In all the divisions of Political Geography, and the inquiries consequent upon their consideration, the province of Statistics must of necessity be trespassed upon. Geography relating to, or rather combining together, all sciences in their relations to the Earth and to man; as in the case of Geology, Meteorology, Ethnology, or any other, so in Statistics, while the application and results of the science will be taken advantage of, they will be dealt with generally and not in detail. In none perhaps are the details so uncertain, in none, perhaps, the general results more satisfactory, more conclusive, or more useful. Materials for statistical calculations exist only in civilized countries, and may, in fact, be considered as no small proof of advanced civilization: their character will vary with that of the people to whom they relate, and be especially influenced by their habits and mode of life. They may be more easily attainable in some countries in the religious, in others in the civil or industrial divisions. In most countries, even the very savage, military statistics can be procured; their existence by themselves is

perhaps to be considered the first advance in civil polity; solitary tribes on the shores of the Polar Sea, of New Caledonia, Africa, Australia, and Terra del Fuego, alone existing without it. Industrial statistics, whether agricultural, commercial, or manufacturing, occupy the second place; social, medical, and educational, the third and most advanced; but the latter of these are closely allied to religion, and religious statistics are evidently independent of advanced civilization. Educational statistics will be found to depend rather on the character of the religion of any country, than either its influence or the extent to which that influence is systematized, from which the statistical accounts of it must in the main result; possibly the most systematic and thoroughly organized form of religion the world has perhaps ever known, the Roman catholic, may be found to have retarded civilization in exact proportion to its domination over its members, the exact and regular working of its machinery, and the consequent amount of statistical knowledge attainable respecting it.

Statistical inquiry, as relating to Political Geography, comprises all calculations of number; under the head Civil, the amount of population in the various divisions; the proportionate number of representatives, if any; of militia, military, or naval force; of taxes, and other public burdens and contributions, may be considered: under that of Industrial, the proportion of population to surface; the numbers employed in various trades and occupations; the products of agriculture, mines, manufactures, and commerce: under that of Religious, the numbers and proportion of the various sects into which the people may be divided. The Statistics of Education and Science will belong to either or all, according to the country under consideration; in Prussia, for example, neither the industrial nor religious can be considered apart from the civil. In all, however, care should be taken not to extend the inquiry beyond its geographical relation.

5 *Of the Order to be observed.*—Of the three divisions which have been recognised, we have placed the Religious first, as being in a great measure independent of the other two; it may be convenient to maintain this order in general description, and to vary it in particular, to take first a general survey of the extent and influence of the different faiths professed by the people of the Earth, and independently of their civil relations, and then to describe more particularly the religious divisions consequent upon them; for while, on the one hand, the principal religious systems of the world extend themselves without reference to political divisions; on the other, the ecclesiastical polity may be distinct from, and independent of, the civil; yet in separate countries, and under distinct governments, it naturally adapts itself to the civil divisions; and in exceptional cases, when it does not, they will probably be found the best, if not the only means by which its limits may be defined. Particular religious belief often attaches itself to particular races, the civil divisions of countries are not unfrequently the consequences of the localization of distinct races, and in this way, again, the religious and civil divisions may be found to coincide.

In the consideration, therefore, of Political Geography in detail, the following sequence of its divisions should be observed: civil, religious, industrial; civil, from the Latin, *civilis*—i. e., appertaining to citizenship, that which belongs or relates to citizens, or its complement—the state.

6 *Of the Civil Divisions of the World.*—The larger civil divisions of the Earth's surface are dependent on the arrangements made by the great human societies which inhabit them for their government, and receive various names, most of which are now used without being limited by strict etymological propriety. The first in rank and importance should be, and in some instances are, termed empires. These are governed by an emperor, in whom is concentrated the authority of the whole, (as the word 'imperator,' first applied to the generals of the Roman armies in the provinces who were the representatives in them of the power of the state, seems to imply.) This word was adopted by those who claimed similar authority to that exercised by the Roman emperors

whether in Italy, Eastern Europe, France, Germany, or Russia. Its import is now very various; it is used equally with reference to Russia, Austria, Brazil, China, and the Island of Hayti, all of which are governed by a ruler styling himself emperor. It is sometimes supposed to express the agglomeration of many separate kingdoms, states, or provinces, under one supreme head; but in this case Great Britain and her dependencies would be the largest and most important empire at present in the world, if not that the world has ever seen. This application of the term is true with reference to Russia and Austria, and partially of Brazil; or more correctly, the Brazils. Great Britain is often termed an empire, but its monarch has not assumed the title corresponding to that designation.

Kingdoms, countries ruled over by a king or queen, (Saxon, *cyng cynig*, German, *konig*, implying military rule,) stand next in rank to empires; yet some kingdoms, as those of Great Britain and France, being of equal, if not superior importance to any existing empires, there is no strict propriety in the sequence. The term monarchy (from the Greek, *μονος αρχος*, monarch—i. e. sole ruler) is applied equally to empires and kingdoms where the supreme power is concentrated in an individual. Monarchies may be hereditary or elective, despotic or limited; the latter are frequently termed constitutional, because the constitution, to which both the monarch and his subjects have subscribed, defines the limits of his power and their obedience. In despotic monarchies, the will of the sovereign is law; in limited monarchies, the law is above all will, and the power of the government is divided between the supreme ruler and the assembled representatives of the other power or powers by which that of the monarch is limited. Parliaments, chambers of peers, senators, deputies, diets, or other names, are applied to these assemblies. They differ much in their constitution and powers; some are hereditary, as the House of Lords, in England; others elective, as the House of Commons. Different qualifications are also required for their members. These varieties of constitution belong to the political history of the world. Political Geography, however, of necessity concerns itself with the great principles on which these varieties are based, as indicative of the origin of the families of mankind in which they are found; the physical character of the country in which they have been educated; or of that in which they are located.

A limited monarchy is, perhaps, to be considered as the agreement of the three great elements of government—the executive, the deliberative, and the suggestive. The first is involved with the monarchical principle, the second with the aristocratic, the third with the representative. The first expresses the will—the second, the mind—the third, the body of the people. When the first predominates, and in proportion to its predominance, the monarchy becomes more and more despotic; the ruler a tyrant, in the original acceptation of the term, (from the Greek, *τυραννος*, implying the rule of an individual according to his own will—i. e., without law;) when the second preponderates, and in proportion to its preponderance, oligarchical, (from the Greek, *ολιγος αρχη*, the rule of the few;) when the latter, democratical, (from the Greek, *δημος*, the people, and *κρατεω*, to rule—i. e., the rule of the many.) In different countries and among different races, we find tendencies to different extremes, as will be hereafter noticed.

It will appear in the sequel that these principles develop themselves co-extensively with corresponding religious and industrial conditions of society, and may be considered partly as consequences of them, partly as resulting from the physical organization of the races adopting them, and partly from the physical character of the country they inhabit, as inducing the corresponding conditions referred to.

Simple despotism appears traceable to the congregating of men in masses: when in cities, as the consequence of democratic ascendancy; among nomad races, of warlike and migratory tendencies requiring a leader. The former is observable in the Greek cities and colonies; the latter, among the Mongul races. The monarchical principle, on the other hand, appears rather the extension of the patriarchal, the king originally having similar jurisdiction to that of a father of a family; it is generally found in connexion with tribal and aristocratic institutions, and has its further development in the constitutional monarchies of Europe, especially in England. Among the ancients, it is to be found among the earliest inhabitants of Greece, the Persians, the Etruscans, probably the Egyptians. It is at present confined almost entirely to the races which have been styled Indo-Germanic or Arian (see *P. G.*, p. 396), of which the Anglo-Saxon is the type. With tribal distinctions, classification of trades and employments, social divisions, as of caste in India, local government, guilds, and municipal institutions, are traceable, as well as a tendency to connect these divisional authorities, whether civil, religious, military, or commercial, with property and tenure of land. The families in which they are found have, therefore, agricultural tendencies, and have taken the lead at a comparatively late period in the history of civilization, their development being slow, their tenacity proportionately great.

Democracy naturally develops itself among commercial and manufacturing communities; its first necessity is numbers confined to a limited space: the apparently exceptional case presented by the United States of America is so only in name, the government of that country being of a mixed character.

The word republic, (from the Latin, *res publica*, commonwealth,) in its ordinary acceptation, implies a government dependent on the will of the people; it is, therefore, properly a democratical form of constitution. Yet Rome, under the empire, was a despotism with republican forms; it had been previously an oligarchy under similar conditions. The word state (from the Latin, *status*, condition,) may be applied to any country having supreme authority within itself; it is generally used with reference to smaller political bodies, especially those united together for mutual advantage; such are those of Central Europe attached to the German empire, such the United States in North America.

The word colony may be applied either to a detached province of an empire, kingdom, or state; a city founded in a foreign country, but preserving its connexion by tradition at least with its parent; or a body of men emigrating from one country to establish themselves in another. Great Britain has her colonies in the first sense in North America, Australia, and New Zealand; in the second, at Aden; in the third, in her emigration and colonizing companies, the first bodies of emigrants sent out by them being often so called. The second was the application more common among the Greeks and Romans; the third has been very general in all ages. In this sense the Flemings founded colonies in England, the English and Scotch in Ireland, the Germans in Hungary and Spain.

The word capital should be applied to those cities in which the government of the country is carried on.

7 *Of the Civil Divisions of Countries.*—Geographically considered, we find under this head—

1st. The limits or boundaries of the country under consideration; the character of the frontier line thus presented, whether natural or artificial; the relation to and points of connexion with the countries by which it is surrounded. These should be considered under this division simply with reference to their general government, and they may have either a military or commercial relation. Artificial frontiers have hitherto required barriers against armed aggression or contraband trade, far more numerous and expensive than natural frontiers. We cannot violate the arrangements made by the Great Creator of the universe without suffering by our folly, and the evil effects of this error are perhaps more apparent and more felt in the character of the people bordering on such a frontier, than in the expense incurred in maintaining it.

Not the least important portion of the frontier of any country is its seaboard, if it have one. The possession of this gives freedom of action and comparative freedom from aggression on that quarter; opens direct communication with countries far distant; and enlarges the sphere of political action. It is the happiness of this country to possess no other, and to it she owes probably much of her political as well as her commercial importance.

As on an inland frontier the lines of fortresses and other artificial defences should be systematically described, so, on a maritime, the ports and harbours available for the outfit and shelter of fleets, the dockyards and arsenals situated upon them, with their relative capacity and importance, as well as the natural or artificial defences of the coast, should be carefully noted.

The points of connexion between neighbouring countries must depend on the natural or artificial means of communication which exist. Rivers, canals, railroads, or great military roads, such as are found in Germany, will therefore come under this head; unless, as in England, most frequently, they have been constructed entirely for the purposes of commercial intercourse.

2nd. The general divisions of the empire or state: if the former, the states of which it is composed first, and then as in the latter when considered separately; the larger and more important division affecting its polity, whether judicial, military, or financial, as in different nations. These greater divisions obtain different names, and as these names are not always applied with strict reference to their meaning or etymology, and indeed are often historical—i. e., the legacies of former ages, and indicative of divisions made originally for other purposes than those for which they are at present used—it is better to consider them all as local terms, and explain them as their use becomes necessary. These first great divisions relating to the general and central government will probably be found susceptible of subdivisions—for example, in England we find first, the division into Shires and Counties, and these again subdivided into Hundreds, Tithings, &c., or Parishes, which are again formed into Unions, and as in military affairs, the larger divisions arranged in Districts.

The cities and towns will be susceptible of the same classification. The metropolis (from the Greek, mother city) belongs, as we have seen, to the first class, as do fortresses, arsenals, and public dockyards; while the principal towns of the larger divisions must be placed in the second.

It is difficult to distinguish exactly between a city and a town. The appellation may be consequent either on law or custom. Blackstone, in the Introduction to his *Commentaries on the Laws of England,* defines a city as 'a town incorporated, which is or hath been the see of a bishop,' and he distinguishes between borough and other towns. 'A borough,' he says, 'is now understood to be a town either corporate or not, that sendeth burgesses to parliament. Other towns there are to the number (Sir Edward Coke says) of 8803, which are neither cities nor boroughs; some of which have the privilege of markets, and some not, but both are equally towns in law.' From the context it appears, that he considered tithings, towns, or vills, to be marked by the possession of a church and the celebration of divine service, the sacraments, and burials; towns or tithings, subsequently called vills, consisted of ten freemen; demi-vills of five, and hamlets of less than five. (*See* SPELMAN'S *Glossary.*) These divisions, as well as their extension to hundreds, and again to counties and earldoms, being of Saxon origin, and the civil being so intimately connected with the ecclesiastical, will show not only that in these acceptations they are originally to be confined to England, but that in them they cannot be now used even here, much less in any other country, and that their application must be governed by custom and analogy. The word town is derived from the Anglo-Saxon, *tynantun;* in the Dutch, *tuyn,* an enclosed place. The word vill (from the Latin, *villa,* a country-house, and having its application originally so confined) has, in modern times, been extended, as in America and the British Colonies, to considerable tracts of land called townships. Geography of course concerns itself principally with the limits of the divisions, and the localities of the cities and towns; their uses belong to Political History. It will be necessary, however, to enter sufficiently into this part of the subject to make the character of the divisions intelligible.

8 *Of Religious Divisions.*—It has been already noticed (see section 5) that the religious divisions of the world have no direct connexion with the political, although they have with those which are consequent on similarity of race. In modern Geography, these are few, easily defined, and extensive in their operation.

They may be characterized in principle as Monotheistic and Polytheistic, it being now generally admitted that no nation or society of men can be strictly termed Atheistic; and Chevalier Bunsen does not hesitate to name religion and language as being the first facts that may be predicated of any nation.

Of the monotheistic systems the principal are Christianity and Mahomedanism, to these may not improperly be added Buddhism, and that of the nations inhabiting America when it was discovered by Europeans. If this classification be adopted, more than two-thirds of the inhabitants of the world may be considered as worshippers of one God. In all these, however, a tendency towards polytheism is apparent among certain nations and families in connexion with a personal, physical, or objective development of the faith professed. It is less observable in the Mahomedan than in the others, because the unity of the Deity is the fundamental article of that creed, but it is found even there in the worship of saints, and the same among the Buddhists. It is the cause of the two great divisions of Christianity, the Roman-catholic and the Protestant, for in this respect the Greek Church may be considered protestant.

Christianity being a religion divulged, not for a race, but for mankind, may and does flourish among all races and families. It has, however, taken deepest root among the Indo-Germanic race already referred to. The Celtic being the more impulsive, are all but universally Roman Catholics; the Teutonic, the more thoughtful, as generally Protestant. The Greek Church (the principal characteristic of which is its entire dependence on a civil head—the Emperor of Russia) has its principal root among the Sclavonic races, remarkable for their subserviency of disposition. Mahomedanism has prevailed chiefly among the races inhabiting south-western Asia and Africa, belonging to the Negritic division, as already indicated. (See *P. G.*, p. 395.) Buddhism is co-extensive in the East with the Mongul race. The other religions of the world appear scarcely capable of enlarged classification, being chiefly traditionary, and unintelligible equally to those professing them as to others.

9 *Of the Dominant Religion.*—Under this head must first be noted the prevalent religion, or that recognised by the civil government of the country, and the principal seats of ecclesiastical power and religious worship. These must of course obtain under different names, according to the nature of the religion and language of the country. The localities of great religious meetings or festivals; of universities or schools devoted principally or entirely to ecclesiastical purposes, or carried on under ecclesiastical supervision and authority, should also be noted. These may, however, belong to the subdivision of this subject, following in natural order, in which the larger ecclesiastical districts of the country are described. This will depend on the character of the supervision exercised, whether general or sectional; it may also be local. The national schools of England partake of all these characteristics,—they are national as under government inspection, or that of the National Society; sectional or diocesan, the clergy exercising so large a share of their direction; local, because in most cases parochial. It will be obviously impossible to enter into such considerations in detail; in most cases it will be possible only to indicate the number, extent, and locality of the minor divisions. Under the second head of this, as in the civil, the chief towns of the subdivisions may with propriety be noticed, whether bishops' sees or otherwise.

10 *Of Religious Sects.*—Having considered the leading or dominant religion in its geographical relation, the sects which may exist in the country

under description must be taken in order of importance; their centre of locality noted, if any; if not, their proportionate distribution. From the circumstances of artificial division already alluded to, it often happens that of the same country politically considered the inhabitants differ essentially in their religious character, and are not unfrequently connected by it more intimately with their neighbours than with their countrymen. This may have an historical explanation, being the result of difference of origin, immigration, or otherwise, or it may be consequent on the physical character of the country: the former is, perhaps, more often the case.

This division of Political Geography, as has been noticed, is not unfrequently found closely connected with both the others; especially it will be observed that civil and religious liberty walk hand in hand, and that their natural consequences are the advancement of education, the increase of agricultural or manufacturing industry, and the extension of trade and commerce.

11 *Of Religious Statistics.*—In this class, as in the preceding, some statistical information should be included. The numbers professing the national creed, and those of the principal sects; the proportion of numbers to area, if any sects be localized, should if possible be ascertained, and the industrial class to which they more particularly appertain should also be noted. From such facts general conclusions of much importance may be drawn. Care must, however, be taken that the inferences be correct; e. g., it might be correct to say that countries professing the Roman-catholic religion are less advanced in civilization than those which have protested against it; it would be incorrect to attribute this wholly to the religion, because those countries which have protested were once of the same faith; the answer must be sought in the connexion between the character of the people and their political and geographical position, resulting in the one retaining, and the other protesting against the faith in question. The cause of religious and social advancement may probably in like manner be found to be the same. In our own country, the manufacturing and mining districts are said to be strongholds of dissent from the established religion; it would be equally incorrect to refer this to any peculiar antagonism to the mode of faith arising out of the habits of the people, or the nature of their occupations; it should rather be attributed to the neglect of those districts by the government and the clergy, except in so far as the kind of labour may influence the development of the mental or bodily faculties respectively, as will be hereafter shown, or as the pursuit of wealth has a natural tendency to draw men away from religion; and thus we find that the employers have taken no care of the spiritual welfare of their workmen, until danger to themselves has arisen from the neglect.

The materials for this division of inquiry into the Political Geography of the world are very insufficient, no good historical and statistical account of the religious systems extant in the world being at present in existence; even the aggregate estimate of the numbers professing the great leading religions of the world being very variously estimated, and details being obtainable only in those countries directly under the influence of the European races, and even in them they are usually very little to be depended upon.

12 *Of the Industrial Geography of Countries.*—The civil and religious divisions of countries have been described as for the most part rather arbitrary than natural, their connexion therefore with Geography proper is rather accidental than essential. The third—viz., the industrial, differs from the others in this, that the localities in which its great divisions are found, have usually a natural relation to them—i. e., the industrial occupations prevailing in them are consequent on their physical character. The truth of this will appear on very cursory inquiry. Land suitable for pasturage is seldom so well adapted, frequently is not at all suited to agricultural purposes. The localities of certain manufactures are dependent sometimes on the presence of the raw material, often, perhaps, on that which is necessary for its conversion to useful purposes. Thus the copper of Cornwall and Australia is carried to

the coal districts of South Wales for smelting; the cotton of America to the neighbourhood of iron and coal for machinery and fuel. In such cases the proximity of good ports and harbours, and their connexion with the interior by rapid and easy transit, both for the importation of the raw material and for the export of the manufactured goods, is indispensable. The rise of such commercial towns as Glasgow and Liverpool is naturally consequent, as are the rapid increase of population and the extension of internal communication. The influence therefore of mineral wealth is most considerable, and among minerals, coal and iron, as of most general application, occupy the first place.

13 *Of Industrial Divisions.*—The leading sub-divisions of this part of Political Geography have been already alluded to, as—1. Pastoral; 2. Agricultural; 3. Manufacturing; 4. Commercial.

These, of course, may frequently be found in close connexion in the same district, but the character of the district will be decided by the predominant industrial occupation.

Each of these must be considered, not only as to its locality, but its character; and as the character of the district and consequent occupation of its inhabitants react upon their character, both physical and mental, it will be necessary to consider them in this relation also.

14 *Of Occupation.*—The amount of mental effort necessary to direct physical labour varies with the nature of the employment. The predominance of the physical over the mental, or *vice versâ*, will produce a development corresponding to the proportion of those influences in the people subject to them.

Speaking generally, labour is not a characteristic of pastoral life; in agricultural, the labour required is rather bodily than mental; in manufactories, the labour employed is certainly skilled labour, but that often more the effect of habit than knowledge or mental effort; and this is especially the case in such as admit of considerable division of labour, more particularly so when the article manufactured is small and made in very large quantities; in such, the people employed may be considered rather as living machines than rational agents. Labour incident to commercial pursuits, especially that of navigation, seems, upon the whole, most conducive to an equal development of mental and bodily energies.

But it is not sufficient to consider the nature of the labour to which different classes are subject, the leisure afforded them must likewise be estimated, as well as their action and reaction on each other. The effect of leisure, like that of labour, differs according to its character and extent. In pastoral life, the labour, if ever considerable, is so only after long intervals of leisure; this leisure is of necessity spent among the works of nature; their contemplation is therefore a general consequence. The motions of the heavenly bodies mark the passage of time and the return of the seasons; the beauties of the Earth and her productions, and the order and harmony of the works of creation, produce corresponding ideas in the mind. Among pastoral tribes and nations, therefore, astronomy, music, and lyric poetry have been most frequently cultivated. The prevalence of leisure among them commonly gives to their relaxation the character of physical labour, and their habits of contemplation and solitude give self-dependence of character while they dispose the mind for the reception of superstitious rites, or even more to a speculative faith. It may be a question whether the peculiarities of their lives do not offer a serious bar to the reception of polytheism and idolatry.

In agricultural life, the regular and continuous strain on the physical powers produces corresponding exhaustion; leisure is used for rest, and enjoyment is customarily sensual. The physical development is in muscular strength, the mental is overpowered by it, the religious belief assumes a personal and sensuous character, and becomes often vulgarly and coarsely superstitious.

In the majority of manufacturing employments, the leisure is more that of the mind than the body, the labour being rather constant than severe; and when the employment assumes the character which has therefore been called mechanical, because like that of a machine, though applicable to a higher class of production, the mind may be entirely abstracted from the labour of the body, and not unfrequently handicraftsmen ply their trade with minds absorbed in mathematical calculations. The more mechanical, therefore, any employment is, the more the mind may be disengaged, and the more varied and extensive will be the mental pursuits of those engaged in it. Such labour is also debilitating to the body; a morbid habit is produced. The tendencies of this class are consequently towards abstruse speculations, mathematics, philosophy, politics. The shoemaker and the tailor may be the rival politicians of the country village. In districts entirely manufacturing, political societies and combinations are commonly found. The morbid temperament consequent on the nature of their employment enlarges real and suggests imaginary evils; nervous irritability takes the place of muscular strength; the enjoyments, often sensual, are chiefly, if not entirely, of a stimulating character; the religious tendencies are speculative, not imaginative; their development, deistic, if not atheistic. These are, therefore, the natural resorts of the political reformer and the religious schismatic.

The labour and leisure consequent on the pursuit of commercial industry are so varied in their character, that in their results they may resemble any or all the other classes. The sailor may, however, be fairly taken as the type of this class. The leisure in his case is similar to that of a pastoral life, excepting inasmuch as it wants most of the beauties, while it abounds in the sublimities, of nature; it produces, therefore, a character imaginative and superstitious, perhaps, but scarcely poetical. The constant realization of danger makes the recognition of a personal providence customary in him, but the equally constant conquest of the dangers to which he is exposed, by science, skill, courage, and physical power, gives him a mental and bodily self-dependence unequalled, perhaps, by any other. Accustomed to discipline, obedience is his political characteristic, though, inasmuch as his life is spent almost entirely apart from civil institutions, he can scarcely be said to have any political creed.

The conclusions which follow on these considerations appear, then, to be, that pastoral life produces a simple, impulsive, imaginative race, possibly deficient in reasoning powers; religious, but superstitious, and not idolatrous; recognising an immediate connexion with the Deity, and therefore conscious of inherent dignity. The political character will be tribal, tending to royalty; the physical, that of energy rather than strength.

The agricultural will be the contrary of this: heavy in body and mind, sensual in character, his religion will be gross—his political habit submissive—his self-dependence that of brute force; he will be the slave of the despot and worshipper of idols.

The mechanical will produce highly-developed reasoning faculties, combined with low physical but highly-nervous energies; the deist and the democrat. Cities, especially manufacturing, have therefore been the originators and supporters of democratic forms of government; then of equality, productive of anarchy, as among the ancient Greeks and modern Italians—the dominion of one, an empire, as in the case of Rome and Paris. Commercial cities have the same general characteristics, softened by more extended intercourse with the rest of the world; and in them the sailor often becomes a political tool, from his habit of obedience and his want of civil associations.

From these it follows, moreover, that countries possessing the most varied physical features produce, on the whole, the most highly-developed race of inhabitants. Such are the countries which have borne, and will continue to bear, rule in the earth. Such were Persia, Greece, Italy; and such, but in a far higher degree, is England. (See Guyot's *Lectures*, c. 1.)

15 *Of the Pastoral.*—The true pastoral districts are those which are only suited to the production of short and sweet herbage, and therefore unfit for tillage, either from the lightness or superficial nature of the soil. It not

unfrequently, however, happens that low lands, on which luxuriant grasses can be produced by irrigation, either natural or artificial, and which could also be made to bear large crops of other vegetables, are devoted to the rearing of cattle. These are not properly to be reckoned in the pastoral districts, and yet they can scarcely be otherwise classed than in them; and a comparison must therefore be instituted between districts of such different character as the downs of Sussex and Hampshire, the hills of Cumberland and Westmoreland, and the rich valleys of Hereford, Somerset, and Devon, and the flats of Lincolnshire.

Land recovered from, or occasionally overflowed by, the sea is often devoted to the feeding of cattle, the saline character of the herbage being, for short periods, very conducive to their health. This again can scarcely be considered pastoral, and with the preceding, while classed among pastoral in its productions, may, in the character of its inhabitants, be rather considered agricultural.

Pastoral countries generally present a nomad population; in them, cities, are of course rare, and the peculiar character of their inhabitants is dependent on that of the animals they rear, and the uses they put them to. The Laplander who tends his reindeer to supply the necessaries of life, differs less from the Arab in this than in the consequences of the climate he resides in, while both perhaps differ equally from the Guacho of the Pampas, who rears his herds of wild cattle to carry on a trade in hides and horns. When therefore these districts come under notice, these peculiarities must be specified. The portions of the world naturally adapted to pastoral life, are usually found between the primary and secondary watersheds of the continents on the side of their least rapid declivity and greatest extension, and form a very large proportion of its surface. They are not, however, fitted to support a population equivalent to their extent. From them, therefore, at various times great emigrations have taken place, which have had a marked effect on the history of the world. Pastoral countries may and usually have agricultural districts within them; countries not pastoral may have districts of that character. The influence on the people will in the one case be general, in the other, local. The social life of pastoral countries has been generally of a patriarchal nature, civil government scarcely recognised; their commerce usually carried on overland by means of caravans; their political combinations can therefore never be elaborate or lasting, their commerce never extensive. As the pastoral habit of life appears to have first prevailed after the Deluge, so the caravan (a word probably of Persian origin) trade seems to have been the first in use. We find it so in all countries in course of settlement, if suitable to it; it disappears with the erection of cities and the establishment of roads, and means of more safe and rapid communication.

16 *Of the Agricultural.*—The agricultural countries and districts of the world are, as the name implies, those which are capable of cultivation by man, upon which he can by manual labour raise vegetables necessary for the support of life, and essential to the arts and requirements of civilization. They are usually found in the valleys of rivers; the richest and most extensive in the alluvial formations about their lower course and beyond the secondary watersheds. Here are to be found the great corn and rice producing countries, those which supply others with the means of subsistence—the granaries of the world.

In a state of nature, those districts of the Earth which are best adapted to agricultural purposes are commonly covered with the heavy growth of vegetable life, often of trees. The character of this growth indicates the quality of the soil, and the nature of the crop it is most calculated to produce. The link which connects these districts with the commercial and manufacturing, is supplied by this circumstance—the agricultural districts requiring the produce of the manufacturing, while these again, not producing food for a superabundant population, must be dependent on them for it. The identity of the interests of all men and their mutual dependence on each other, thus appear to be the natural order of creation.

The agricultural districts are those which follow in course of settlement on the pastoral. Their settlement of necessity raises the question of tenure of land. The modes in which land may be held by individuals may be reduced under two heads; the one in which the occupier is the owner of the soil, the other in which he pays rent for his occupation. These have been considered respectively characteristic of different races of men, possibly they are rather distinctive of different stages of progress. Tenure by military service, the basis of the feudal system, and one form of tenure by occupation, has prevailed wherever the Indo-Germanic race has been diffused, and by its prevalence marks it as migratory and aggressive. We first read of rent for land in the book of Genesis, where Joseph bought all the land of the Egyptians for Pharaoh, and let it again to the Egyptians for a fifth part of the produce. (Gen. xlvii. 24.) These two modes of tenure, producing very different effects on an agricultural population, are important to be noticed in Political Geography.

It is, as has been observed, in districts of this character that cities have first arisen; in them, man being stationary, property has increased, and with the increase the mechanical skill of man has been developed to supply his artificial wants, the result of riches and society; a marked distinction thus arises between the dwellers in towns and the agriculturists—a distinction which becomes more marked in proportion to the increase of wealth and population.

The nature of the agricultural produce of any district must have its effect on the people inhabiting it, not only because of the difference of climate and soil necessary to the production of different plants, but of the effect which those used for food may have on the physical energies of the people. Thus, the corn-producing countries will be more favourable to physical development than the rice-producing. It is necessary also to consider whether the vegetable produce of the Earth be directly employed in manufactures, or transported for that purpose, as at present the three great staples, cotton, flax, and hemp are.

The transport of heavy raw material to a distance, for the purpose of manufacture, is evidence of a great advance in the industry of the countries engaged, especially that in which it is manufactured. It may also be taken as an indication that there is a surplus beyond the produce required for the food of the people. The returns will, therefore, be in manufactures or money, and the balance in favour of the country exporting.

17 *Of the Manufacturing.*—Manufactures are, in the early stages of civilization, carried on among a nomad or an agricultural population; they become localized when either the division of labour for their conduct on a large scale becomes necessary, or the presence of the raw material attracts them to any particular place. Since the extensive use of machinery in all manufactures, they have had a tendency to gather round the coal and iron producing districts; the facilities of transport afforded by railroads may have a tendency to disperse them again. At present, however, these minerals must receive special notice in connexion with the distribution of manufacturing industry over the face of the globe.

When the agricultural produce of any district is employed in neighbouring manufacture, the one is supported and enriched by the other, but it more often happens that the increase of manufactures in any district has a tendency to destroy its agricultural character. This happens especially in districts, the mineral wealth of which is the subject of manufacturing industry—and this, if only from the necessity of finding place for the refuse which has been brought to the surface with the desired mineral. In some mining districts, the coal in particular, the *disposition* of this rubbish is a problem often difficult and always expensive in its practical solution. But in any case, the necessities of a dense population, whether real or artificial, the supply of the wants of the poor and the luxuries of the rich, must reduce considerably the agricultural capabilities of the district.

It is also a question of importance whether the manufactures of any country are for home consumption or for exportation; if the former only, they must be very limited in extent; if the latter, they will of course be enlarge to meet the demand made for the article produced. The consequence will be a return trade and enlarged commercial relations; and here also a reactionary tendency may be observed, since much of this return trade will be in agricultural produce for the food of the manufacturing population.

The congregation of men in manufacturing districts, and the tendency of these employments to lower the amount of agricultural produce to be obtained for them, will thus compel a trade in articles of food; but as the food-producing countries are usually in a low stage of civilization, their consumption of manufactured articles is limited, and commerce therefore flows in two channels. The presence of mineral wealth is dependent on geological formation, by it the localities of certain manufactures are of necessity determined; and here also, as in the other divisions, we see the nature of the country influencing, if not determining, the character and occupation of its inhabitants.

18 *Of the Commercial.*—Commerce is dependent on manufactures; it is either internal or external, maritime or over-land. Commerce is the exchange of surplus commodities; even where it is carried on with a circulating medium on one side, this is strictly true; there must then be a surplus of money.

These exchanges can only be made between places where the surplus is different. The commercial relations between different parts of the world are, therefore, determined by the character of their productions. Commerce is therefore, in its geographical distribution, not the result of accident, but subject to fixed laws.

The paths of commerce also are regulated by physical causes. The caravan trade of old was carried, as it is now, over table-lands, deserts, and prairies. The passes of the mountain chains have directed it first into certain districts, and brought those thus connected by the head-waters of their rivers into early and most immediate commercial relations. In maritime commerce, islands and inlets of the sea had an early share, voyages were then made across the ocean, but even its broad expanse did not give unlimited facilities for traffic. There also physical difficulties formed barriers, imperceptible indeed, but still effective. Currents and trade-winds directed commercial intercourse into certain channels, from which not even steam navigation has materially diverted it. The extension of railway traffic seems, however, likely to bring back much of the commerce of the world into the old overland routes, and by making speed the first element in the calculation, to invest those parts of the continental masses that approach nearest to each other with an importance they have not enjoyed since the earliest periods of commercial enterprise, as affording the more immediate means of communication.

From what has been already said, it will be apparent, that, as extent is the result of elevation, or in other words, the horizontal development of the land is the consequence of its vertical contour, upon this also depends the distribution of animal and vegetable life over the surface of the earth, the variety of produce of different countries, their consequent relative value as a residence for man, and the commercial relations which may exist between them, and no less the physical development of man himself, his habits of life, employments, and mode of thought, and hence, in no small degree, the character of his religious and political life—upon this also has depended the distribution of mankind over the Earth, both in time and space, the earlier or later peopling of different districts, the source from whence they have been peopled, and the paths of migration,—these have had their own proper effect on the history of the world, specially in the diffusion of language and literature—have made the western part of the old continent progressive, while the eastern has remained stationary, if it has not retrograded.

The presence of minerals and metals has also been shown to be dependent on the same cause, being found only in certain parts of the geological series. They are available only when those portions are presented. The rocks which have been formed by fluvial deposit, and especially the coal measures, could only have been so formed in entire or partial basins, and their localities have therefore been determined by vertical contour at the period of their formation; while those minerals and metals which are formed in connexion with rock of earlier place in the series, are only available for the purposes of man where they make their appearance above or through the others. The localities of manufacturing and mining industry have therefore been pre-arranged by the same cause. It has been shown that commercial exchanges are the result of variety of produce, that this variety is the consequence of variety of contour, that the paths of commerce by land are determined by, and that those by sea have been, and are now dependent on the same causes. It has also appeared that all these have a reciprocating effect on each other; for not only do manufactures encourage and develope agriculture, if not at home, of necessity elsewhere, that commerce arises and is maintained by the variety of supply and demand; but that different kinds of manufactures and variety of commercial intercourse, as well as of agricultural produce, stimulate and encourage those with which they are connected; and thus it becomes apparent that countries possessing the greatest physical development are capable of the greatest industrial development also. The knowledge therefore of vertical contour must be the basis of all true geographical knowledge, and from the consideration of its effects we must conclude that the Great Creator in giving form to the Earth disposed certain causes to necessary ends, and that in this disposition he proposed the ends to which he has adapted the means, and that we, as parts of his creation, more especially those to whom as his intelligent servants he has given the rule and use of his inferior creation, shall act most to his glory, and best fulfil the conditions of our own existence, when we direct our actions, whether political or social, with an intelligent appreciation of them; and that his original designs and beneficent intentions towards the world cannot be fulfilled by us, until we know, appreciate, and apply to their proper purposes, the capabilities, not of one but of all countries, until we consider not only what one country may be made to produce, or what one people are capable of producing, but how the produce thus obtained will affect other countries, how advantage may result to others also; in short, till the good of the many be consulted, instead of that of the few, and we fulfil generally, as well as particularly, the royal law, to do to others as we would have them do to us.

To this desired consummation, the knowledge of geography in its highest relations is necessary. This can only be attained by careful initiation into its elements. The importance of the end to be attained may well stimulate to more laborious and uninteresting investigations than this science requires.

END OF PART I.

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